1C

Vol. XXIV, B, No. 2 August, 1954

JOURNAL

OF

THE MADRAS UNIVERSITY

CONTRIBUTIONS IN MATHEMATICS, PHYSICAL AND BIOLOGICAL SCIENCES

PUBLISHED BY THE UNIVERSITY
MADRAS

COMMONWEALTH MYCOLOGICAL INSTITUTE
8 JAN 1955

INSTRUCTIONS TO AUTHORS

Three numbers of the Journal are published every year, in April, August and December respectively and contributions for publication should be sent to the Editor not later than February 1, June 1, and October 1 respectively.

Contributors are requested to be clear and concise. Manuscripts should not exceed 8,000 words and should be in a final form for the press. Each paper should start with a short summary which should be an abstract of the whole paper, complete and clear in itself, and not over 3 per cent. of the length of the paper. The introduction and reviews of literature should be restricted to closely pertinent papers.

The manuscript should be typewritten on one side of the paper only, with wide margins and be double spaced throughout including titles, footnotes, literature citations and legends. Symbols, formulae and equations must be written clearly and with great care. Scientific names of genera and species are printed in italics and should be underlined in the typescript. Too many tables, graphs, etc. should be avoided. Each table should be typed on a separate sheet with its proper position marked in the text in pencil.

Literature citations: All references to literature cited in the text should be presented together at the end of the paper in alphabetical order of authors' names. Each reference should be given in a standard form as follows: (1) name(s), followed by initial(s), of author(s); (2) year of publication in brackets; (3) full title of paper; (4) title of journal, abbreviated according to *World List of Scientific Periodicals*, 1952, and underlined; (5) volume number in Arabic numerals, underlined with two lines to indicate bold type; (6) page numbers without the prefix, p. When books are mentioned in the references, the order should be: name of author(s), initial(s), year in brackets, title of the book, which should be underlined, volume number, edition, page, followed by place of publication and name of publisher. Where a reference has not been seen in original, it should be indicated by an asterisk and the name of the abstracting journal or other source should be mentioned in brackets. If the title is in a language other than English, the diacretic signs, etc., should be precisely given as in the original.

Examples:

Text: (Patel, 1948) ; but, e.g., 'Patel (1948) showed that . . . .' . For two authors, write as, e.g., Khanna & Sharma (1947), using the ampersand (&). If there are more than two authors, all names should be given when cited for the first time and thereafter the first name only, adding *et al.*

References:

Raman, C. V. (1949) The theory of the Christiansen experiment. *Proc. Indian Acad. Sci.*, A, 29: 381-90.

Sahni, B. (1936a) Wegener's theory of continental drift in the light of Palaeobotanical evidence. *J. Indian bot. Soc.*, 15: 31-32.

Sahni, B. (1936b) The Karewas of Kashmir. *Curr. Sci.*, 5: 10-16.

Drawings should be on white board in India ink. As many of the illustrations as possible should be grouped together so that they may be reproduced as a single cut. Photographs should be glossy prints with strong contrasts. They are best submitted in the exact size in which it is desired to have them reproduced. Full page drawings and photographs should be made so as to allow reduction to a maximum size of 8" × 5". The name of the author, figure number and the title of the article should be written in pencil on the back of each figure. Each figure should have a legend. Legends should be typed on separate sheets.

Contributors will receive only a galley proof and *no alterations should be made at the proof stage.* 25 reprints without covers are supplied free to authors. Extra reprints may be had at cost price, but this should be ordered when returning the corrected proof.

Communications should be addressed to Professor T. S. Sadasivan, Editor, Journal of the Madras University (Section B), University Botany Laboratory, Madras-5, India.

Vol. XXIV, B, No. 2 August, 1954

JOURNAL

OF

THE MADRAS UNIVERSITY

"Mode of Citation: *J. Madras Univ.* B"

Editor

PROFESSOR T. S. SADASIVAN

Editorial Board

PROF. C. P. GNANAMUTHU, M.A., D.Sc. F.Z.S.
DR. V. S. KRISHNAN, M.A., D.Sc.
DR. D. V. RAJALAKSHMAN, M.A., M.Sc., PH.D.
DR. P. R. JAGAPATHI NAIDU, M.Sc., PH.D.
DR. M. SANTHAPPA, PH.D. (Manchester), PH.D. (Lond.).
PROF. G. N. RAMACHANDRAN, M.A., PH.D., D.Sc.
PROF. P. S. SARMA, M.Sc., PH.D.
PROF. M. A. GOVINDA RAO, M.A., PH.D.
PROF. K. N. MENON, M.A., PH.D.

Issued on 22-9-54

PUBLISHED BY THE UNIVERSITY
MADRAS

CONTENTS

THE DIGESTIVE SYSTEM OF MUGIL CRENILABIS (FORSK)
By S. Mahadevan .. 143

ECOLOGY AND SEASONAL SUCCESSION OF THE ALGAL FLORA OF A SALT MARSH AT MADRAS
By V. Krishnamurthy .. 161

HETEROCYCLIC COMPOUNDS, PART III
SYNTHESIS OF SOME BROMO-QUINAZOLONES
By M. R. Subbaram .. 179

HETEROCYCLIC COMPOUNDS, PART IV
SYNTHESIS OF SOME IODO-QUINAZOLONES
By M. R. Subbaram .. 183

THE SEASONAL VARIATIONS AND THE SUCCESSION OF THE FOULING COMMUNITIES IN THE MADRAS HARBOUR WATERS
By A. Daniel .. 189

DYKE ROCKS OF PALLAVARAM
By N. Leelananda Rao .. 213

PLAGIOCLASE FELSPARS FROM CHARNOCKITES OF SALEM
By S. Ramanathan .. 225

COMMENTARIA HERBARII
By S. Rajan .. 237

BLUISH-GREEN HORNBLENDE FROM AN AMPHIBOLITE OF JALARPET
By V. M. Raghavan .. 245

THE DISTRIBUTION OF t_1 AND ITS APPLICATIONS
By N. Marakathavalli .. 251

A CHARACTERIZATION FOR COMPLETE BOOLEAN ALGEBRAS
By V. K. Balachandran .. 273

KINETICS OF REACTIONS BETWEEN CHLORIDE RADICALS FROM PHOTO-EXCITED ION-PAIR $Fe^{+3}Cl^-$ AND VINYL MONOMERS IN AQUEOUS SOLUTION
By M. Santhappa .. 279

REVIEW .. 297

J. Madras Univ., B, XXIV, No. 2, pages 143-160, 1954

The Digestive System of Mugil Crenilabis (Forsk.)*

— a plankton feeder.

BY

S. MAHADEVAN

(Zoology Laboratory, Madras University)

(Received for Publication, February 3, 1954)

ABSTRACT

The gross anatomy and histology of the digestive tract of *Mugil crenilabis* (Forsk.), a plankton feeder, is fully described.

INTRODUCTION

In a previous paper the digestive system of *Caranx djedaba* (Forsk.) and *Trichurus haumela* (Forsk.) was described in detail. The present paper, the second in the series, deals with that of a plankton-feeder, *Mugil crenilabis*. The digestive systems of *Etroplus suratensis* (an omnivorous feeder) and *Osphronemus goramy* (a herbivorous feeder) which have also been studied will be published later, together with a detailed discussion on the salient features noted among the various types of feeders.

The entire work was carried out at the suggestion of Dr. C. P. Gnanamuttu, in the University Zoology laboratory and I owe my debt of gratitude to him for his guidance, criticism of the work and for his valuable suggestions. I place on record my sense of gratitude to the Madras University Syndicate also for awarding me a studentship, during the tenure of which the present work was carried out.

DIET

Chacko (1949) found *Mugil* to be a plankton feeder. In the present study the stomach contents of about 200 fish were analysed

* Formed part of the thesis approved for the M.Sc. degree of the University of Madras.

and noted to be mainly composed of planktonic organisms which are listed below :—

Thalassiothrix spp., *Coscinodiscis* spp., *Navicula, Pleurosigma, Megalopa, Nauplii, Mysis, Leucifer, Acetes* etc. The rest of the items were in a semidigested form, in a suspension of fluid and could not be properly identified. Hence, it may be accepted that *Mugil* is a plankton feeder.

Gross Anatomy

The mouth opening is very narrow with a moderate gape which is not more than ·75 cm., in a fish which measures 14 cms. in length. The mouth is bounded by lips, of which, the upper is thicker. The premaxillae or the maxillae do not show any trace of teeth at all. The total absence of teeth on the jaws is peculiar. The lower jaw is slightly larger and hence the mouth opening faces upwards. This suits the planktonic feeding habit of the fish. The jaws are capable of a slight protrusibility. The buccal cavity is lined throughout by mucus membrane which is thrown into a set of longitudinal folds (Fig. 1b). The folds along the floor and the sides of the buccal cavity are not well marked; only that of the roof being visible when examined with a hand lens. The tongue is very rudimentary, a thin portion being free anteriorly and the rest attached to the floor of the buccal cavity. The buccal cavity which measures only 1 cm. in a fish 15 cms. long, starts immediately posterior to the lips and extends upto the beginning of the first pair of gill arches.

The buccal cavity leads into the pharynx which commences from the first gill arch and extends as far as the last arch. Four gills hang down on each side of the pharynx. On each gill arch are two rows of long, closely arranged gill-rakers. Of these, the outer row close to the operculum is better developed. The long, whip-like gill-rakers which are set closely are an adaptation to the filtering mode of feeding of the fish. As will be noted from the analysis of the stomach contents, the fish is mainly a plankton feeder and the micro-organisms of the plankton are conveyed by the water. The water is allowed to escape through the gills while the closely set rakers act as a sieve-plate in filtering these food particles from the water and retaining them. Such a process is assisted by a copious mass of mucus found over the gills. The

planktonic organisms become stuck to the mucus and are thus detained.

On the pharyngeal roof are noticed two cushion-like structures which are slightly convex. These cushions are formed by the fusion of the pharyngobranchials of the gill-arches. They bear small closely arranged and numerous villiform teeth. The cushions fit exactly into the concavity found on the floor of the pharyngeal cavity. This cavity is borne by a triangular plate formed by the fusion of the inferio-pharyngeals of all the gill arches. There are no teeth in this concave region. The pharynx becomes narrower posteriorly, leading finally into the oesophageal tube. The entire pharynx is lined by a thin, white mucus membrane. No longitudinal fold could be made out either with even a hand lens.

The oesophagus is cylindrical in shape and extends backwards and opens into the stomach which makes an angle with it (Fig. 2). The oesophagus measures 1·1 cms. dorsoventrally and ·75 cm. along the dextro-sinistral axis. On cutting open the oesophagus, deep and close longitudinal folds are seen. The anterior boundary of the oesophagus could be determined rightly as commencing where the longitudinal folds begin to appear distinctly. The posterior boundary is where it opens into the stomach. The stomach is of the 'caecal' type as in the other fish studied (viz., *Caranx* and *Trichiurus* L). But it is peculiar in appearing as a simple bag, connected to the oesophagus on the one hand and the duodenum on the other hand (Fig. 2). But a free hand section taken longitudinally shows the real caecal nature and the two cardiac and the pyloric portions. Where it joins the oesophagus, the lumen is narrow and dilated into a large cavity—the cardiac part—and is continued into a large slender tube the pyloric part (Fig. 3). This pyloric part is thick and muscular, appearing like the gizzard of the fowl. The closely arranged longitudinal stomach folds are deep and flap-like, and converge towards the pyloric orifice, thus narrowing the lumen. In this region the walls become thickened due to the musculature. Owing to this great thickening of the walls, the folds appear flatter and the lumen of the pyloric stomach becomes constricted; just anterior to the opening of the pyloric stomach into the intestine, the lumen becomes a very narrow passage. This pronounced development of the musculature of the pyloric stomach is significant, as it may probably help the trituration of semi-digested food. A similar structure was found to occur in

Mugil cephalus by Ishida (1935b) who points out the resemblance to the gizzards of birds, though he considers that physiologically a stomach is absent. The pyloric orifice is a minute opening at the centre of a thin membrane. Except for this thin, flexible flap, round the orifice, there is no pyloric valve. It is probable that this membranous flap can be thrust back easily in only one direction.

The duodenum begins from the pyloric opening and is a thick, bent portion of the intestine with five pyloric caecae opening into it. The caecae are separate from one another, not arranged in a definite order, opening by means of independant pores into the proximal end of the duodenum. The *duodenal* duct also opens here by an extremely small pore which conveys the bile juice into the lumen of the intestine. The duodenum makes a bend and leads backwards. The intestine is long and thrown into loops. It is with great care and difficulty that these intestinal loops were uncoiled, as all along the intestinal wall, fatty tissues hold the coils closely (Fig. 1a). The intestine is one and a half times longer than the body-length of the fish; this seems to be an average ratio for considerable number of fishes examined. The intestinal loops are accommodated within a narrow body cavity which is not even one fifth the length of the intestine. Altogether the intestine makes six or seven sharp loops before it reaches the anal outlet. The anus is situated just in the middle of the body of the fish ventrally and is oval in shape. The intestine when split open longitudinally shows the presence of the longitudinal folds which are feeble and noticeable only under a hand lens. The folds are well marked and deep in the pyloric caecae. A rectum could not be differentiated externally or by an internal ileorectal valve or by the thickness of the musculature. But it was observed that the last portion of the intestine (about 2·5 cms.) show a thick coating of mucus along its wall. Probably this may be the rectal region, as such a coating of mucus is not seen anywhere in the intestine. In a fish 15·5 cms. long with a buccal cavity 1 cm. long and a gape of 1 cm. the pharynx measures 2·5 cms. in length, the oesophagus 1·3 cm, the stomach 1·5 cm. and the intestine 28·5 cms.

Histology

(a) *Buccal cavity*: The buccal wall consists of the following layers; the mucosa including the stratified epithelium, the basement membrane and the stratum compactum and the submucosa.

1. *Mucosa*: The mucosa consists of the stratified epithelium which lines the buccal membrane and is supported beneath by a thick stratum compactum. The mucosa rests upon a well-developed connective tissue layer which lies close to the stratum compactum and is areolar in nature further beneath. The stratified epithelium is almost regular all along, consisting of 8 to 9 layers of cells which vary in shape in different positions. The lower most layer consists of short cuboidal or columnar cells. The tips of these cells are either rounded or pointed. The nuclei are very large and spherical or oval in outline, with distinct chromatin network. The next layer also shows resemblance to the basal layer. Superficial to these cells are layers of irregular cells and polyhedral cells intermingled. These cells are firmly put together so that there are no intercellular spaces seen. The superficial cell layer is composed of cells which are compressed horizontally (i.e.,) flattened and scale-like. Their nuclei are elliptical. These cells stain more deeply than those below. Except the basal layer, all the cell layers on the sides of the longitudinal folds are of flattened cells with their nuclei also flattened.

The presence of mucus-secreting cells is a notable feature of this fish as also of others. They are of the pyriform type, 16 μ by 6 μ in size and are found at the topmost row of the stratified epithelium, occurring either at the top or at the sides of the folds (Fig. 4). Most of the cells were crumpled, probably due to the discharge of the mucus through the wide pore of the mucus cells. The cells stain bright red with Thionin and stain positively with Mucicarmine.

Perhaps the most notable feature of the epithelium is the presence of the taste-buds (Fig. 5). They are found on the floor, sides and roof of the buccal cavity. The taste-buds show localization occurring only on top of the folds and the papillae and also along the sides but never in the crypts of the folds. There may be two or even three taste-buds found on the papillae. The taste-bud is spheroidal in shape and measures about 30 μ by 18 μ. It is built of a number of elongate cells, with elliptical or ovoid nuclei occupying the broadest portion of the cells. These are the 'gustatory' cells and they all converge towards the free extremity, terminating near a small pit. Such hairlets, as described by Sarbahi (1940) and Al-Hussaini (1945) were not seen here. There is another set of cells bordering the taste cells which are also elongate

in nature, probably akin to the 'sustentacular' cells referred to in connection with the higher mammals, which support the 'gustatory' cells and give a definite shape and cover the taste-buds. The base of the bud rests upon a papilla-like projection, especially so, on the top of the folds. This papilla-like projection is formed of the evaginations of the underlying stratum compactum and submucosa. Close to the base of the bud are seen blood capillaries penetrating the connective tissue.

The stratified epithelium is supported by a thin membrane, made up of closely packed fibres and staining uniformly throughout. This is the basement membrane. Below this is the stratum compactum, composed of fibres densely packed, wavy in its course. This stratum is as thick as the stratified epithelium itself, and the entire layer is pushed out wherever the connective tissue below forms the papillae.

2. *Submucosa*: This layer is built up of connective tissue fibres which are closely set below the stratum compactum and areolar in nature deeper down and contain numerous blood vessels and a few nerve fibres. The submucous papillary projections, so, serve as a supporting core to the taste-buds, carrying blood supply and the nerves to these structures.

In some sections, examined, there are found some groups of cells within the stratum compactum, in the meshes of submucosa. The nuclei of these cells are similar to those of the intermediate layers of the stratified epithelium. In tangential sections taken in a series, these cells slowly make their way into the epithelium. The significance of these cells is not known.

(b) *Pharynx*: The wall of the pharynx is made up of mucosa, submucosa and muscularia. The constituent layers forming the wall of the pharynx are uniform throughout. Hence the division of the pharyngeal wall into the central, the anterior, the posterior and the lateral regions can hardly be accepted here, as was made by Curry (1939) in *Cyprinus carpio communis.*

1. *Mucosa*: This is divisible into three structures as in the buccal mucosa. It is thrown into a number of longitudinal folds which are high and hence the crypts enclosed are narrow and deep. The stratified epithelium, lining the mucosa, consists of 10 to 14 cell layers. On the roof of the pharyngeal wall there are

only 6 or 7 layers and the folds are low and broad, enclosing shallow crypts. The basal layer of the stratified epithelium consists of low columnar cells, their nuclei being oval and staining lightly. These can be easily differentiated from the rest of the cells above, which are irregular in outline and have small, round or spherical nuclei staining deeply (Fig. 6). The cell boundaries of most of these cells are indistinct. Superficially, large number of mucus-secreting cells are found, as also noted by Al-Hussaini (1945, 1946, 1947), Dawes (1929), Rogick (1931), Curry (1939) and McVay and Kaan (1940). These mucus cells are much larger than those of the buccal cavity and are pyriform. Along the oesophageal boundary, they are longer than broad with the broad end (towards the lumen), gradually tapering to a point posteriorly where the small spherical nuclei are situated. Mucus cells are seen in regular rows along the folds and measure about 30 μ by 16 μ. The stratified layer of cells are less and show a decline in number of rows posteriorly.

The taste-buds are similar in structure to those of the buccal cavity but are numerous especially on the cushion-like structures of the roof and less so on the floor. All the taste-buds are located on the top of papillae without exception, but all the papillary structures do not bear taste-buds. The taste-buds are flask-shaped and measure 22 μ by 18 μ in thickness. The concentration of large number of buds on the pharyngal cushion, obviously, helps this plankton-feeder to select the planktonic organisms rejecting the inorganic matter and large sand grains. Such a condition was also reported by Al-Hussaini (1947) in *Atherina*, a plankton-feeder.

The stratified epithelium rests on the basement membrane as in the case of the buccal cavity and is supported further by the stratum compactum below. Mallory's triple stain brings out the closely arranged, uniform fibres of the stratum compactum as wavy, blue, ribbob-like structure, excellently.

2. *Submucosa*: This is the thickest envelope of the pharyngeal wall and is one and a half again as thick as the mucosa. The connective tissue nuclei are small, spherical and deeply staining. The papillary structure bearing the taste-buds at their tops are mainly formed due to the thrusting out of these connective tissue fibres pushing out the stratum compactum also. Occasionally, muscle fibres belonging to the muscularis layer enter into the

submucosa in all directions. These muscle fibres, however, are of the striated variety and form a definite layer outside the submucosa.

3. *Muscularis*: The muscularis consists of only circular fibres which are rarely coarsely striated and is twice as thick on the roof as on the floor of the pharynx, helping the dorsal cushion in working against the floor.

(c) *Oesophagus*: This is compressed dorsoventrally so that the diameter of a section of the oesophageal tube in a dorsoventral plane is less (about 1·5 mm.) than in the horizontal plane (3·5 mm.) which is constant throughout. The oesophageal wall is made up of mucosa, tunica propria, submucosa, muscularis and in the hind region, a thin serosa is added to these layers.

1. *Mucosa*: This is single layer made up of the columnar epithelium and is the continuation of the stratified epithelium of the pharynx. The columnar cells measure about 21 μ by 1·5 μ with their oval nuclei situated in the basal half of the cells staining slightly (Fig. 8). Among the columnar cells are seen some mucus cells of the goblet type which are by no means numerous. The goblet cells disappear posteriorly leaving the entire epithelium made up of columnar cells. There are no leucocytes seen wandering into the epithelium and a basement membrane could not be made out, the entire columnar cells resting on the tunica propria directly.

2. *Tunica propria*: This is made up of areolar connective tissue which is noticeable in possessing numerous blood capillaries. The tunica propria supports the primary and the secondary folds. That the blood vessels reach the columnar epithelium is suggestive of the fact that absorption may take place even in this region itself.

3. *Submucosa*: This is very similar to tunica propria and difficult to distinguish but for the fact that in the meshes of the submucosa are scattered numerous longitudinal muscle fibres, closely arranged and striated, penetrating even the tunica propria (Fig. 7).

4. *Muscularis*: Mainly consists of circular, striated fibres and is very thick. This may help the fish in preventing the food from regurgitation and help in the smooth swallowing of food by alternate contraction and expansion. The longitudinal fibres

which are found strewn in the meshes of the submucosa do not form themselves into a regular layer.

5. *Serosa*: This is present only posteriorly (towards the stomach region) and is very difficult to make out since it is thin. It is made up of pavement epithelium with deeply staining nuclei. The subserous tissues found here, underneath, hold blood vessels which penetrate into the muscle layer.

The transition from the oesophagus to the stomach, is gradual. In serial sections examined, gastric glands appear with the disappearance of the striated muscle fibres. The epithelium, however, at this stage is purely columnar, with no trace of goblet cells intermingled. The oesophageal tunica propria, which was invaded by fasciculi of longitudinal muscle fibres, is very thin. The muscle layers are also organized into an outer longitudinal and an inner circular layer, both of them of the unstriated type.

(d) *Stomach*: The longitudinal folds of the oesophageal wall is continued into the stomach. The folds are very prominent and closely arranged. Though a gross examination (vide supra) shows no distinction into a cardiac and a pyloric part, a careful examination of a longitudinal section and histological studies show that within the stomach the large spaceous cardiac part is well marked from the narrow pylorus.

Cardiac stomach: The mucosa (consisting of the superficial epithelium and the glandular epithelium), tunica propria, submucosa, muscularis and a serosa constitute the wall of the cardiac stomach.

1. *Mucosa*: The entire mucosa is lined by superficial epithelium which is columnar in nature beneath which is found the gastric epithelium (Fig. 9).

Superficial epithelium: This is made up of cylindrical cells. But due to the close arrangement of cells in certain areas especially at the crest of the folds, the cells appear differently, being pear-shaped, giving the appearance of 'fan-like' arrangement of the cells. The cells are columnar on the sides as well as on the crypts (Fig. 10). Their nuclei are oval situated at the basal half of the cell and stain lightly. The cells at the crest of the folds are not typically columnar and have central nuclei. Whereas Dharmarajan (1936) found the cells at the crest staining vividly, the

author found them stain as lightly as the cells of the crypts and sides of the folds.

Mucus was found to be adhering to the free border of the cells and filling the crypts between the folds. The presence of this mucus layer protects the epithelium from the sand grains and other coarse gritty particles which the fish may take in along with its diet.

Glandular epithelium : This is composed of numerous tubular glands which are short near the cesophageal wall and numerous near the blind end. The adjacent glands are bound by connective tissue septa (Fig. 9). The gastric glands are made up of few cells arranged end to end so as to form a long tubular structure enclosing a lumen in the centre. In a cross section the cells composing the glands are polygonal in outline. On an average 8 to 16 cells are arranged radially to form a gland (Fig. 11). There is a fairly wide lumen left in the middle. The nuclei of the cells are spherical and placed eccentrically away from the lumen of the glands. The cytoplasm of the cell is heavily granular which are best seen in sections stained with Mallory's triple stain. The nuclei stain lightly and the granules brownish. The glands open into the stomach at the crypts of the folds. These openings are seen in section taken near the 'fundus' of the stomach. In such places, the tangential sections across the gland reveal, one end of the gland blind while the other end communicates with the lumen of the stomach. The cells lining the opening of the gland into the crypts are similar to those found composing the gland and there is no differentiation of 'neck cells' or 'mucoid cells'.

The blood supply to the mucosa is significant. Fine capillaries extend throughout the subepithelial coat of the connective tissue, branching to form a network of small vessels between the peptic glands and submucosa.

2. *Tunica propria*: This is found external to the glandular layer supporting the primary folds and is made up of a network of thick strands interlaced with one another. These strands penetrate the glandular layer and lie lodged in every available space between the glands. Evidently, the function of this tissue is to serve both to bind the gland and also to form a support to the glandular layer. The strands penetrate also the secondary folds below the glandular epithelium. The blood supply, as already mentioned,

is very great and suggests the absorptive function of the stomach. Inside, nearer the circular muscle fibres, connective tissue fibres are densely arranged.

3. *Submucosa*: The densely arranged connective tissue fibres found beneath the muscularis and above the tunica propria is limited in its area and this is the submucosa.

4. *Muscularis*: The muscularis consists of an outer longitudinal bundle and an inner circular bundle of muscle fibres which are of the unstriated type. The circular muscle fibres are twice as thick as the longitudinal. Both are well vasculated.

5. *Sercosa*: This is a single layer and thicker than the oesophageal serosa. The coat is made up of flat cells with elliptical, deeply staining nuclei.

Pyloric stomach: The pyloric stomach, unlike what is found in other fishes, appears bound up with the cardiac to form a single bag-like stomach. But it can be distinguished from the cardiac, by the narrow lumen, by the absence of glandular epithelium and by the extraordinary development of the musculature. The pyloric stomach wall is made up of mucosa (consisting of the superficial epithelium alone), tunica propria, submucosa, muscularis and a serosa.

1. *Mucosa*: The mucosal folds are prominent, deep and close but near the pyloric crifice they are almost smoothed out and the mucosa is uniform. The epithelium is simple and columnar in nature. The columnar cells are slender with their basal oval nuclei, staining lightly. Copious quantities of a peculiar variety of mucus which sets to form numerous fibres closely packed, result in the formation of a membrane which protects the pyloric stomach from the coarse sand particles and is secreted by the epithelium itself.

2. *Tunica propria*: This is similar to the cardiac stomach, in structure except that the strands are closely packed and the area occupied is less.

3. *Submucosa*: This is thin and indistinguishable.

4. *Muscularis*: The muscularis of the pyloric stomach is four times thicker than that of the cardiac stomach and is prominent by reason of its thickness. The inner circular muscle fibres contribute to the enormous thickness of the muscularis. The closely packed bands of circular, unstriated fibres give the stomach a gizzard-like

structure, referred to in the gross anatomy. Similar observation is made by Ishida (1935b), in *Mugil cephalus,* wherein he notes a thick horny epithelium as in the gizzard of birds. This cuticle is a secretion of the stomach and served to protect the epithelium against the silt engulfed with the food organisms. It thus appears to be a structural adaptation against the hard material which would otherwise rupture the stomach. The gizzard of this plankton-feeder, studied by the present author, also helps to triturate the food organisms along with the gritty matter and mixes the food effectively. Such an efficient milling device probably explains the poor dentition. Besides this grinding action the gizzard, by the contraction of its wall, can push the food in the direction of the duodenum. The longitudinal muscle fibres are very much reduced.

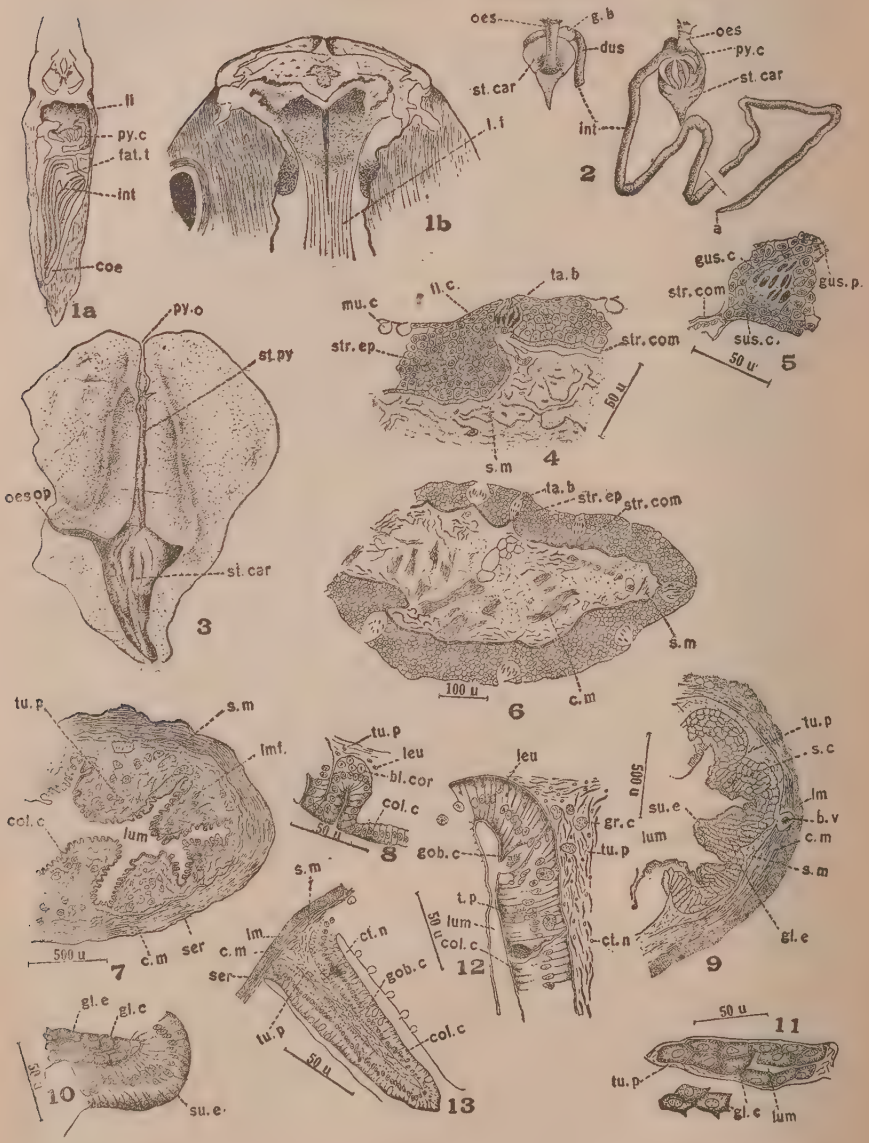
5. *Serosa*: The serosa is of clear, pavement epithelium with nuclei flattened and deeply staining.

(e) *Intestine*: The anterior part of the intestine (more accurately called the duodenum), middle intestine or ileum, the posterior intestine and the rectal region are all fundamentally similar in structure and consist of the same layers throughout, with only minor variations. The intestinal folds are markedly well developed. The folds of the duodenal region are tall, slender and numerous with pointed crests. All of them are longitudinal in direction and arranged uniformly. The base of the fold is broader than the crest of the folds. In the middle intestine the folds are wide apart, not because the folds are fewer but because the intestine seems to have flattened in this region and the folds obliquely placed. Near the posterior region, the folds are broad, flat and fewer.

1. *Mucosa*: The longitudinal folds are lined by epithelium which is entirely columnar in nature. The cellular constituents are not complex, there being not more than two types of cells. The most typical is the columnar cell (Fig. 12). The other type is the mucus-secreting cell. There are small leucocytes wandering as well as some granular cells invading the epithelium. The columnar epithelial cells are high and typically cylindrical measuring 22 μ in length by 2 μ in breadth. The nucleus is oval in shape showing distinct chromatin network. It is situated in the basal half of the cell. A thin laminal border lines the epithelium. This thin sheet is striated in appearance and forms a top plate covering the columnar cells which probably secreted it. Here and there, on this

lining, interspersed among the regular columnar cells, are apertures for the flow of mucus thrown out by the goblet cells. Dawes (1929) noted a peculiar staining effect in the intestinal epithelium of *Pleuronectes*. Tissues fixed, during a prolonged resting phase, in Bouin's fluid sectioned and stained in Delafield's haematoxylin, show a deep blue spindle-shaped mass about three times the length of the nucleus situated about the middle of the cell. The present author stained sections of this region of *Mugil crenilabis* by the same technique and did not observe the deep blue spindle-shaped mass. The mucus-secreting cells have a typical goblet outline being constricted at the middle and tapering caudalwards into the filamentous process where the oval or the spherical nuclei are situated in a mass of cytoplasm. These goblet cells open into the lumen by small pores. Each cell measures 59 μ long by 6.1 μ broad. The goblet cells are found in plenty in duodenum and out number even the columnar cells. In the middle intestine they were found to have decreased in number. But, however, sections taken behind the constricted part of the intestine, referred to in the gross anatomy, reveal abundant goblet cells as in the case of duodenal region. Probably this proliferation of mucus cells explains the presence of so much of mucus noted here during the dissection, helping the efficient defaecation of food material. Wandering laucocytes are seen commonly between the epithelium from the inner to the outer limit of the columnar cells. The nuclei are large, staining black with the haematoxylin, spherical but smaller than the oval nuclei of the columnar cells. Some granular cells seem to have worked out their way into the epithelium from the tunica propria. The dense granular cytoplasm of these cells stain brownish with Mallory's triple stain.

2. *Tunica propria*: This consists of a richly vascular areolar connective tissue continuous with that of the submucosa running parallel to the circular muscle layer. The tunica propria supports each fold and is considerably thick. In the case of the rectal region it occupies a greater area. In addition, the blood vessels penetrating the tissue is significant. The food materials which are not absorbed pass into the reticulum of the areolar tissue layer and thus directly into the blood stream. There are no 'villi' and 'lacteals' in the areolar tissue. Scattered in the tissue are numerous, small, oval or spherical, deeply staining connective tissue nuclei. There are some migrated granular cells similar to those found in the epithelium. The granular cells are spherical with heavily granular


li
py.c
fat.t
int
coe
1a
l.f
1b
oes
g.b
dus
st.car
int
2
oes
py.c
st.car
a
py.o
st.py
oesop
st.car
3
mu.c
li.c.
ta.b
str.ep
str.com
s.m
4
gus.c
str.com
gus.p.
sus.c.
50 u
5
ta.b
str.ep
str.com
s.m
c.m
100 u
6
tu.p
s.m
lmf.
col.c
lum
c.m
ser
500 u
7
tu.p
leu
bl.cor
col.c
50 u
8
s.m
lm
c.m
ser
ct.n
gob.c
col.c
tu.p
50 u
13
leu
gob.c
t.p
lum
col.c
50 u
12
500 u
su.e
lum
gr.c
tu.p
ct.n
tu.p
s.c
lm
b.v
c.m
s.m
gl.e
9
gl.e
gl.c
50 u
10
50 u
11
tu.p
gl.c
lum

EXPLANATION OF TEXT FIGURES

1a. Alimentary canal of *Mugil crenilabis*, in situ.

1b. Buccal roof of *Mugil* to show the longitudinally for the membrane × 3·5.

2. Outline drawing of the alimentary tract.

3. Free hand, longitudinal section through the stomach of *Mugil*. × 3·5.

4. Transverse section through the buccal wall, showing the stratified epithelium.

5. A taste bud from the buccal epithelium.

6. Transverse section through the roof of the pharyngeal wall.

7. Transverse section of the oesophagus to show the arrangement of the different tunics.

8. Epithelium of the oesophageal mucosa.

9. Transverse section of the cardiac stomach.

10. Superficial epithelium of the cardiac stomach.

11. Cross section of the gastric gland.

12. Transverse section through the intestinal fold showing the columnar epithelium and the goblet cells.

13. Cross section through a fold in the middle pyloric caecal region.

KEY TO LETTERING

a	= Anus.	leu	= Leucocyte.
bl. cor	= Blood corpuscles.	li	= Liver.
b.v	= Blood vessel.	lm	= Longitudinal muscle.
coe	= Coelom.	lmf	= Longitudinal muscle fasciculi.
col. c	= Columnar cells.		
ct. n	= Connective tissue nuclei.	lum	= Lumen.
duo	= Duodenum.	oes.	= Oesophagus.
fat. t	= Fatty tissues.	oes. op	= Oesophageal opening.
fl. c	= Flattened cells.	py. c	= Pyloric caecae.
g. b	= Gall bladder.	s. m	= Submucosa.
gl. c	= Glandular cells.	ser	= Serosa.
gl. e	= Glandular epithelium.	su. e	= Superficial epithelium.
gob. c.	= Goblet cell.	tu. p	= Tunica propia.
int	= Intestine.		

cytoplasm and excentrically placed spherical nuclei. Surrounding the folds and below the circular muscle fibres, the tunica propria insensibly merges with the submucosa.

3. *Submucosa*: This is composed of tissue fibres which are very closely packed and is much restricted in its area.

4. *Muscularis*: The muscularis is almost uniform throughout. In the rectal region it is thicker than before. Probably this may act as a 'sphincter.' The muscularis is made up of an outer longitudinal layer and an inner circular layer, both of them of the unstriated variety.

5. *Serosa*: The appearance of the serosa is thin but distinct, made up of a single layer of flattened cells with flattened nuclei, staining deeply. The subserous connective tissue is seen binding the serosa and making interstices in the longitudinal bundles.

(f) *Pyloric caecae*: These are identical in structure with the duodenum into which they open. It has been said of the intestine that it is not only an organ of storage of reserve food materials but also an organ serving for secretion and absorption. Hence these caecae are also as much concerned with storage, secretion and absorption as is the duodenum. The longitudinal folds are similar to those of the intestinal wall, proximal to the openings of the pyloric caecae. The folds near the mouth of the caecae resemble those of the duodenum while those near the blind end of the caecae resemble the folds of the middle intestine. These folds do not show complexity in form such as the 'cobweb' pattern found by Rahimullah (1945) in *Ophiocephalus marulius*. The lumen of each caecum is reduced by the folds. Nevertheless they look like 'pockets of the intestine' into and out of which food can readily pass.

1. *Mucosa*: This is exactly similar to that of duodenum being made up of columnar cells intermingled with goblet cells (Fig. 13). The goblet cells are never absent anywhere in the caecae but are uniformly distributed throughout. Rahimullah (1945) observed ciliated epithelium in the pyloric caecae of *Scorpoena spp.* and *Mullus barbatus* etc. But no such ciliated epithelium was observed in the case of *Mugil*. The absence of any other gland and the presence of the goblet cells aid in the secretion of mucus alone but not of any kind of notable digestive enzyme.

2. *Tunica propria*: This is equally well developed and highly vascular as that of the intestinal wall.

3. *Submucosa*: The submucosa is also relatively thin and consists of a loose network of connective tissue fibres, including a few blood capillaries and nerves.

4. *Muscularis*: The muscularis is comparatively thinner than that of the duodenal wall. The longitudinal muscle layer is only a third of the size of the circular muscle layer.

5. *Serosa*: This is not very distinct.

REFERENCES

Al. Hussaini, A. H. (1945) The anatomy and histology of the alimentary tract of the coral feeding fish *Scarus sordius.* (Klunz.) *Bull. Inst. d'Egypte,* 27.

—— (1946) The anatomy and histology of the alimentary tract of the bottom feeder, *Mulloides auriflamma* (Forsk.) *J. Morph.* 78: 121-153.

—— (1947) The anatomy and histology of the alimentary tract of the plankton feeder, *Atherina forskali.* (Rupp.) *Ibid.* 80: 251-286.

—— (1949) On the functional morphology of the alimentary tract of some fish in relation to difference in their feeding habits. *Quar. J. micr. Sci.* 90: 109-139.

Chacko, P. I. (1947) Food and feeding habits of the fishes of the Gulf of Manaar. *Proc. Indian Acad. Sci. B.* 29: 83-96.

Curry, E. (1939) The histology of the digestive tube of the carp. (*Cyprinus carpio communis*). *J. Morph.* 65: 53-78.

Dawes, B. (1929) The histology of the alimentary tract of plaice (*pleuronectes platessa*). *Quart. J. micr. Sci.* 73: 243-274.

Dharmarajan, M. (1936) The anatomy and histology of the alimentary system of *Otolithus ruber* (Bl. schn.) Part II, Thesis submitted to the Madras University (unpublished).

Ishida, J. (1935) The stomach of *Mugil cephalus* and its digestive enzymes. *Annot. zool. Japonensis.* **15**: 158-160.

Mackay, J. A., & Kaan, H. W. (1940) The digestive tract of *Carassius ouratus*. *Biol. Bull., Woods Hole,* **78**: 53-67.

Mahadevan, S. (1950) The Digestive system of *Caranx djedaba* (Forsk) and *Trichiurus haumela* (Forsk). *J. Madras Univ. B.* **21**: 25-48.

Rahimullah, M. (1941) A comparative study of the morphology, histology and probable functions of the pyloric caecae in Indian fishes, together with a discussion on their homology. *Proc. Indian Acad. Sci. B.* **21**: 1-35.

Rogick, M. D. (1931) Studies on the comparative histology of the digestive tract of certain teleost fishes II. A minnow (*Compostoma anomalum*). *J. Morph.* **52**: 1-25.

Sarbahi, D. S. (1940) The alimentary canal of *Labeo rohita* (Hamilton), *J. Asiatic Soc. Bengal,* **5**: 87-116.

J. Madras Univ., B, XXIV, No. 2, pages 161-178, 1954

Ecology and Seasonal Succession of the Algal Flora of a Salt Marsh at Madras *

BY

V. KRISHNAMURTHY
(Department of Botany, Presidency College, Madras)

(Received for publication, April 23, 1954)

ABSTRACT

An account is given of the ecology and the seasonal succession of the algal flora of a salt marsh connected with the mouth of the river Adyar at Madras. Six algal communities are distinguished, viz., (1) *Chaetomorpha-Gracilaria* community, (2) *Acanthophora-Hypnea* community, (3) *Polysiphonia* community, (4) *Rosenvingea* community, (5) *Enteromorpha-Cladophora* community and (6) Diatoms-Blue-green algae community. Of these communities, (1) and (2) are abundant throughout the year, (3) and (4) occur twice during the year and (5) and (6) occur only once during the year.

With respect to each community, the following details are given: (1) the algal composition of the community, (2) the dominant form or forms, (3) seasonal succession and (4) mode of perennation.

The seasonal succession of the communities is correlated with the changes in the salinity of the water in the marsh.

It is suggested that the algal flora of the marsh was derived from algae which were brought in by currents in the sea, from distant places during the monsoon and which had found their way into the marsh during high-tide, when the river is connected with the sea.

Although extensive work has been done on the ecology of freshwater algae as well as marine algae, only a few papers have been published on the ecology of the algae of salt marshes. An important piece of work on the algae of salt marshes was that of Carter (1932, 1933) who gave an account of the algal flora of two salt marshes at Canvey and Dovey in England. Chapman (1941) has summarised all the available literature on the algae of salt marshes up to 1941.

* This paper formed part of a thesis approved for the Degree of Master of Science of the University of Madras.

In India, though some work has been done on the marine algae (Boergesen, 1930, '32, '33, '37, '38; Anand, 1940, '43; Srinivasan, 1946), very little work has been done on the algae of salt marshes. M.O.P. Iyengar & G. Venkataraman (1951) recently contributed a paper on the ecology and seasonal succession of the algal flora, and in particular, the Diatomaceae, of the river Cooum, at Madras. In

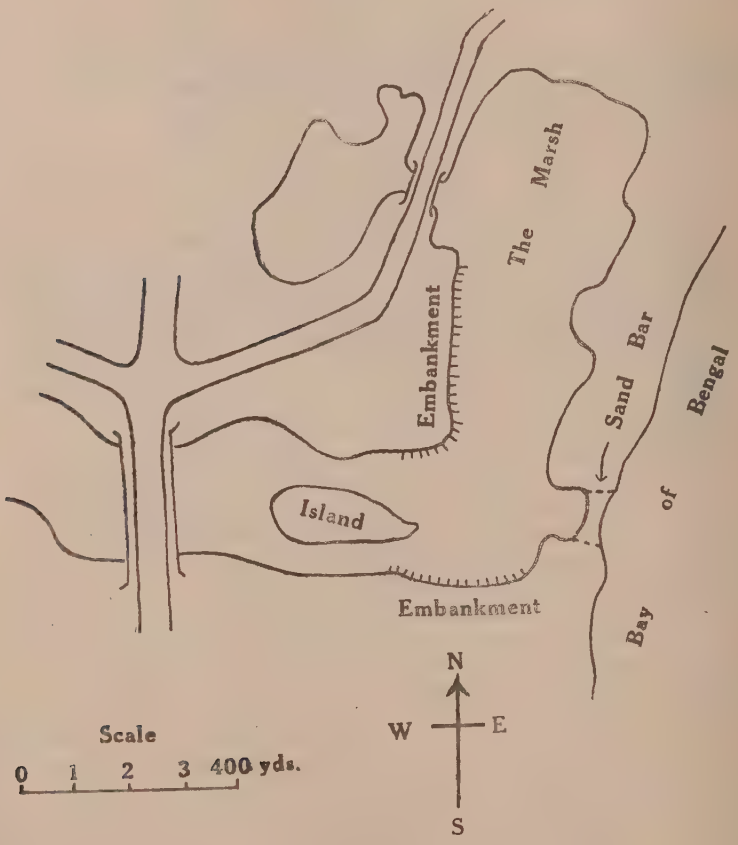


Fig. 1. Map of the estuary of the river Adyar at Madras.

this paper, the algal flora of the rivermouth and a portion of the river has been dealt with. In the present paper, an attempt has been made to study the ecology and seasonal succession of the algal flora of a salt marsh at Madras.

The salt marsh in question is connected with the rivermouth of the river Adyar, and runs for a distance of about three furlongs to the north of the rivermouth, more or less parallel to the sea and separated from it only by a distance of about a hundred yards (Fig. 1). Since the marsh is connected with the rivermouth, any change in the level of the water in the rivermouth brings about a corresponding change in the level of the water in the marsh also. For the major part of the year, a sand-bar separates the rivermouth from the sea and there is no flow in the river and so the water in the river is practically stagnant throughout. During very heavy rains, the river gets flooded and the sand-bar is removed and the river water flows into the sea. The river is connected with the sea for some time and when the flow in the river stops completely, the sand-bar becomes established, cutting off the river from the sea once again. During the short period when the river is connected with the sea, the tidal action of the sea causes a corresponding rise and fall in the level of the river water in its estuarine region. Since the marsh is connected with the rivermouth, the marsh also shows a corresponding rise and fall in its water level.

Methods of Study

The algal vegetation in the marsh was under observation for a period of twelve months from May, 1949, to May, 1950. The marsh was visited every fortnight and, during each visit, a collection of the various algae in the marsh was made. Detailed notes were also made in the field on the various algal communities, the extent, location and distribution of each community, and also of each of the more important species. As far as possible, the phase of life-history of each alga at the time of collection was ascertained by microscopic examination in the field. A portion of the algae collected was fixed in the field in form-acetic alcohol, and the remaining portion was brought to the laboratory in the living condition, and examined in further detail. Samples of the marsh water were collected at the same time and later analysed for salinity (total dissolved solids) and pH value.

The algal flora in the marsh was correlated with the chemical and physical features of the water and the prevailing meteorological data. The latter data were obtained from the Regional Meteorological Centre at Nungambakkam, Madras (Fig. 2).

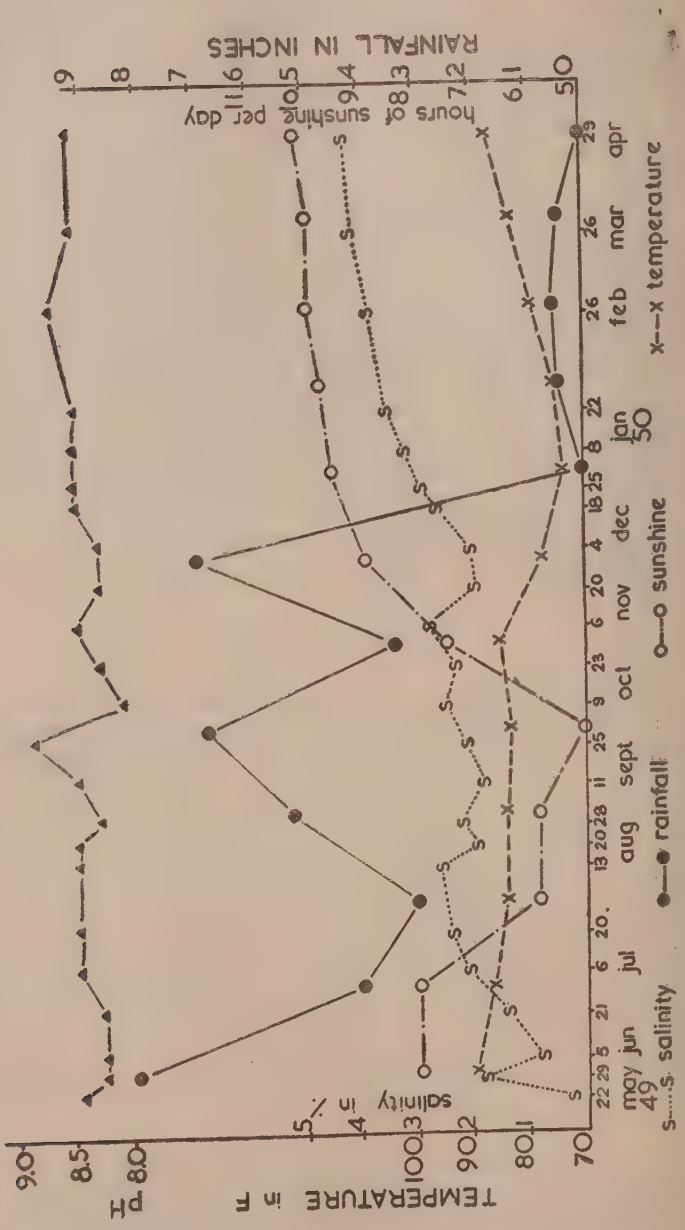


Fig. 2. Meteorological and chemical data for the year 1949-50.

The Salinity of the Water

On 21st May, 1949, there was very heavy rain, amounting to 7.2 inches. As a result, the river got flooded and the level of the water in the marsh rose very high. The salinity of the water in the marsh was very low, being only 0.25%. The sand-bar at the rivermouth was removed that day and the water was flowing freely into the sea for about a week. When the flood subsided, the flow of the river water into the sea finally stopped. After this, owing to the coming in of seawater during high-tide periods, the salinity in the river water began to increase gradually. Since the marsh is connected with the rivermouth, the salinity of the marsh water also correspondingly increased. The river was connected with the sea for nearly two months up to the end of July, 1949, when the sand-bar became established once again. After the sand-bar was formed, the water in the river, and consequently in the marsh also, was free from the influence of tidal changes in the sea. From July, 1949 to October, 1949, the salinity of the water in the marsh ranged from 1.8% to 2.8%, the salinity going down when there was a rainfall and rising again when there was no rain for a considerable number of days (Fig. 2). In October, the monsoon set in and the river became flooded again. As a consequence, the water level and the salinity of the water in the marsh went down to nearly 2%. The sand-bar in the rivermouth was removed and the river water flowed into the sea. After the flow in the river stopped, owing to the coming in of seawater during high tide periods, the salinity of the water in the rivermouth and consequently in the marsh, gradually began to rise. This continued up to January, 1950. After January, 1950, the sand-bar became established once again. But the salinity still continued to rise. This increase in salinity was evidently due to the gradually increasing temperature in the months of January, February and March, and the consequent increased evaporation of water from the marsh.

The pH value of the water in the marsh ranged from 7.8 to 9.0. The lowest pH value (7.8) was recorded on 9th October, 1949 and the highest (9.0) on 11th September, 1949.

The Algal Communities

The following are the chief algal communities that could be distinguished in the marsh:

A. *Algal communities which were abundant throughout the year.*

1. *Chaetomorpha- Gracilaria-* community.
2. *Acanthophora- Hypnea-* community.

B. *Algal communities occurring twice during the year.*

1. *Polysiphonia-* community.
2. *Rosenvingea* community.

C. *Algal communities occurring only once during the year.*

1. *Enteromorpha- Cladophora* community.
2. Diatoms—Blue-green algae community.

A list of the algae occurring in the marsh is given at the end of this paper.

A. *Algal communities which were abundant throughout the year.*

1. *Chaetomorpha- Gracilaria* community:

This community consisted of *Chaetomorpha littorea* Harv., *Gracilaria confervoides* Grev. and *Chaetomorpha tortuosa* Kütz. Of these, the first two were abundant while the third occurred only as stray filaments in between the tangles of *C. littorea.* The tangled filaments of all the three algae were found submerged as well as free floating in masses at the surface of the water.

Chaetomorpha littorea formed large irregular floating masses. The exposed upper parts of the masses were pale yellow in colour and were showing signs of disintegration. Among the submerged portions of the alga, the filaments which were more towards the surface of the water were dark green in colour and those which were lower down were more grass green. The stray filaments of *C. tortuosa* inside the masses of *C. littorea* were bright green in colour.

Gracilaria confervoides was very abundant and formed large tangled masses, often forming thick submerged felts. At the beginning of July, 1949, small fragments of the alga were constantly being washed ashore. Later on in the month, fragments of this alga were seen attached to the leaves of *Halophila ovalis* Hook. f.

which were just coming up. The alga was attached to the host by means of discs which were developed from parts of the branches. The thallus of the alga after attachment very often grew in a stoloniferous manner forming new discs (Figs. 3, 4). Later on, the older branches of the alga became detached and were free floating. The alga then grew as smaller or larger free floating masses.

The thallus of the alga is cylindrical and branched freely. The alga, moreover, was curled. The upper exposed portions of the masses of the alga were pale green in colour while the submerged portions of the alga were dark purple in colour. The alga multiplied mainly by fragmentation of the thallus. Reproductive structures were generally lacking. Occasionally, however, cystocarps containing ripe carpospores were found on the alga.

In June, July and August, 1949, the alga became loaded with numerous epiphytes, comprising chiefly, *Cocconeis littoralis, Achnanthes brevipes* var. *intermedia, Tabellaria fenestrata* and the endophytic alga, *Endoderma viride.*

2. *Acanthophora- Hypnea* community:

This community consisted of two members of the Rhodophyceae, viz., *Acanthophora spicifera* (Vahl.) Boergs. and *Hypnea valentiae* (Turn.) Mont. Of these two, *Acanthophora* was more dominant. The two algae occurred together throughout the year in the marginal portions of the marsh and were completely submerged under water.

In May and June, 1949, the two algae were found in small floating masses. After every rain, a large quantity of these algae was washed ashore. In August, 1949, fragments of their thallus were found attached to leaves of *Halophila* and other objects in the water such as shells, stones etc., in the marginal portion of the marsh. The forms were attached by discoid holdfasts formed on those portions of the thallus which were in contact with the object. These attached thalli were not sporelings of the alga, but were merely fragments of the vegetative thallus which had become attached to the various objects in the water. The marsh was searched for sporelings of these algae, but without success.

After August, 1949, for about two months, both floating as well as attached clumps of these two algae were seen near the edge of the marsh. Later on, when the thalli became too old, they broke

away from their attachment. During the hotter months, these algae gradually dwindled and almost disappeared.

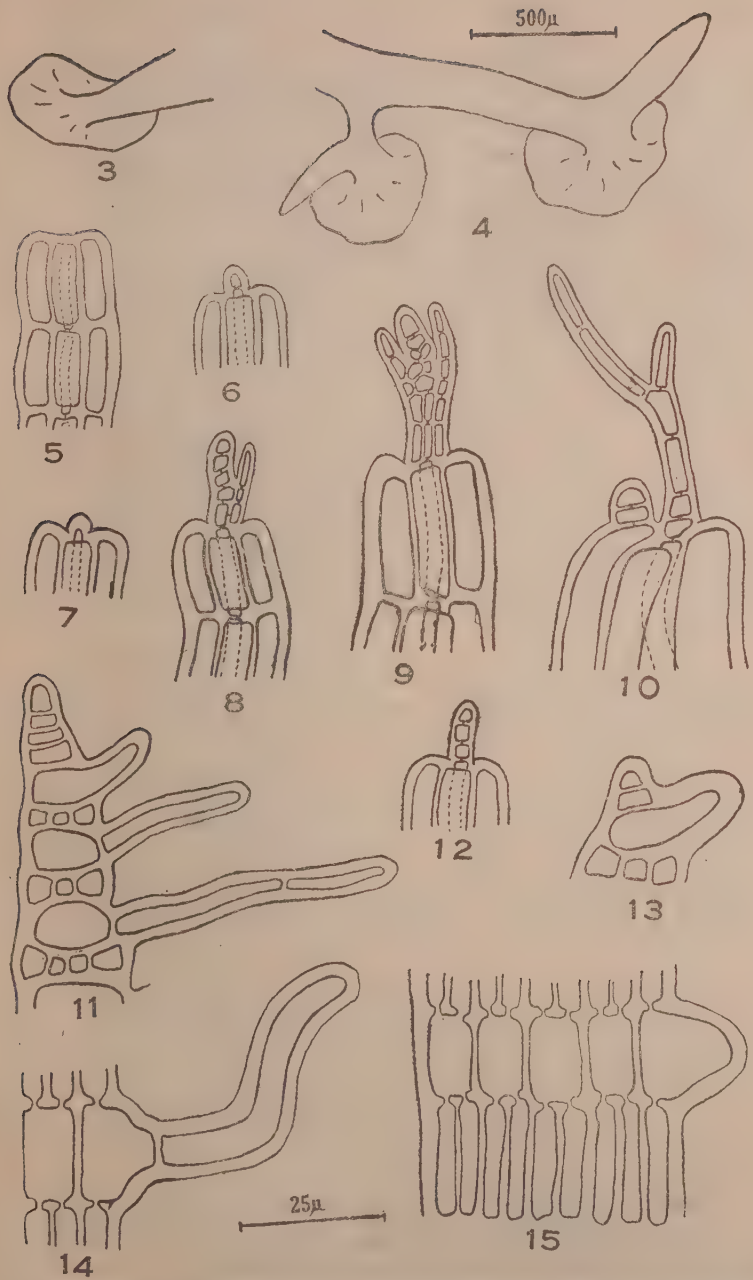
Hypnea was sterile throughout the period and multiplied purely by fragmentation. *Acanthophora,* however, formed tetraspores in November and December, 1949.

B. *Algal communities occurring twice during the year.*

1. *Polysiphonia* community:

This community was dominated by *Polysiphonia platycarpa* Boergs. It occurred as an epiphyte on *Halophila ovalis* Hook. f. and *Cymodocea isoetifolia* Aschers. Along with this alga occurred *Spyridia filamentosa* (Wulf.) Harv. as stray unattached clumps. Both these algae were occurring together in the marsh in May, 1949, and again from July to October, 1949. In November, 1949, the two algae disappeared from the locality. In March, 1950, *Polysiphonia* was again seen growing in the marsh, but *Spyridia* was absent.

In May, 1949, *Polysiphonia* was growing abundantly as an epiphyte on *Halophila ovalis* and *Cymodocea isoetifolia.* At this time the alga was sterile. There was very little water in the marsh at this period. After some heavy rain on 20th and 21st May, 1949, the water level rose in the marsh and the *Halophila* and *Cymodocea* plants with the epiphytic *Polysiphonia* were submerged. After some time, when these submerged host plants were examined, no *Polysiphonia* could be found on them. The epiphytic *Polysiphonia* had evidently broken away from its host plants. The detached individuals of the alga, however, could not be found, although a search was made for these in the different parts of the marsh. In June, 1949, young plants of *Halophila* had established themselves near the water margin. These plants were at first free from epiphytes. But in July, 1949, *Polysiphonia* was found growing again on the leaves of these plants. These *Polysiphonia* individuals, when examined under the microscope, proved to be fragments of old thalli which had floated on to the *Halophila* plants and got attached to them by means of secondary rhizoids. Some of these fragments had cystocarps with ripe carpospores. Evidently, the detached portions of the old thalli did not die out, but were growing unattached in the marsh and became wafted ashore and got attached to the plants of *Halophila.*



Figs. 3, 4. *Gracilaria confervoides*, fragments showing development of attaching discs Figs. 5-10, 12. *Polysiphonia platycarpa*, stages showing development of new branches by proliferation Figs. 11, 13-15. *Spyridia filamentosa*, development of secondary rhizoids

These attached fragments gave rise to proliferations which soon developed into new branches. The process of proliferation was followed in some detail. In the terminal segment of the attached fragment, the pericentral cells were found to have grown slightly longer and over the terminal exposed portion of the central cell and were completely covering it. Thus the broken end of the fragment was healed and well protected. Moreover, the outer gelatinous layer of the thallus also extended over the apex and formed an additional protection (Fig. 5). During proliferation, the central cell elongates and pushes its way between the pericentral cells and protrudes at the apex (Fig. 7). This protruding portion of the central cell is then cut off by a cross-wall, and forms an apical cell. This apical cell is dome-shaped (Fig. 6) and undergoes transverse divisions giving rise to a row of discoid cells (Fig. 12). These discoid cells undergo periclinal divisions and give rise to the characteristic filament of the alga (Figs. 8, 9). In one rare instance, the apical cell of the proliferating filament was cut off from a pericentral cell (Fig. 10). The proliferations grew very well and soon gave rise to reproductive structures.

Towards the end of July, 1949, and in the first week of August, plenty of germlings were also found growing on the host plants along with the older thalli.

In September and October, 1949, the alga attained its maximum abundance and covered extensive areas in the marsh. In November, 1949, the alga dwindled and finally disappeared. The alga reappeared in March, 1950, and continued to grow in the marsh till the end of the period of investigation. During this period, the alga was only in a vegetative condition.

The older plants of *Polysiphonia* became loaded with epiphytes. As chief among the epiphytes may be mentioned, the diatoms, *Tabellaria fenestrata, Achnanthes brevipes* var. *intermedia, Cocconeis littoralis* and *Lycmophora abbreviata. Lyngbya* spp. were also abundant, while *Endoderma viride* was commonly present within the gelatinous outer layer of the thallus.

Spyridia filamentosa occurred as stray filaments among the clumps of *Polysiphonia* during the months of August, September and October, 1949. The alga also occurred as free floating fragments. No germling was observed in the marsh and the fragments of the alga were evidently those which had broken away from older

thalli. These fragments had formed some rhizoids, but no attached plants were observed. Two kinds of rhizoids were formed by them, (1) those which had developed from the axial cells of the younger portions of the filaments and (2) those which had developed from the cortical cells of the older portions of the thallus. In the case of the first kind of rhizoids, the axial cell forms a tubular lateral protruberance (Fig. 13). This protruberance elongates considerably and is then cut off by a cross-wall forming a rhizoidal cell (Fig. 11). This rhizoidal cell, then, by a series of transverse divisions, forms a septate rhizoid (Fig. 11). In the case of the second kind, the rhizoid develops from the cortical cells of the older portions of the thallus (Figs. 14, 15), but the further development is quite similar to that of the first kind.

The alga produces plenty of tetraspores during the period of its occurrence in the marsh. But no sexual structures were observed in any of the specimens collected. The alga disappeared along with *Polysiphonia* in November, 1949, and did not come up again during the rest of the period of this investigation.

2. *Rosenvingea* community:

During certain periods of the year, *Rosenvingea intricata* Boergs. formed a pure community, which was rather extensive. The alga was first observed as a free floating form in May, 1949. It was common along the water margin and was often partially exposed. The alga disappeared in June and was not seen in the locality again till November, 1949. From November, 1949 to February, 1950, it was very abundant. Towards the end of February, 1950, it dwindled again and finally disappeared. It reappeared in April and was fairly common towards the end of the period of this investigation. During the period between November, 1949 and February, 1950, the alga produced plurilocular sporangia in abundance.

C. *Algal communities occurring only once during the year.*

1. *Enteromorpha—Cladophora* community:

This community was present in the marsh from July, 1949 to February, 1950. It was composed of *Enteromorpha compressa* (L.) Grev. var *lingulata* (J. Ag.) Hauck, *E. prolifera* J. G. Ag. var. *tubulosa* (Kütz.) Reinbold, and *Cladophora sp.* From July to November, 1949, *E. compressa* was the dominant form, while *Cladophora* was rather infrequent. Towards the end of October, *Cladophora* rapidly increased in number and in November, 1949, it

reached its maximum abundance. In December, 1949, *Enteromorpha compressa* dwindled and *Cladophora* became the dominant form. In January, 1950, *E. compressa* could be met with only as stray individuals here and there in the marsh. In February, *Cladophora* also dwindled gradually and by the end of that month, disappeared completely. Throughout the period, *E. prolifera* occurred as a subdominant form and disappeared from the marsh along with the other members of the community in February, 1950.

2. *Diatoms—Blue-green algae community*:

This community occurred in two situations, (1) on moist soil near the water edge and (2) on *Halophila* and *Cymodocea* as epiphytes.

On moist soil: The community in this situation flourished from June, 1949 to February, 1950. Some time after heavy rains, when the level of the water in the marsh was slowly going down, the moist soil near the water edge was seen covered with a golden green film. This film consisted mostly of a number of diatoms and some blue-green algae. In August, 1949, *Cocconeis littoralis* Subrahmanyan, *Nitzschia closterium* (Ehr.) W.Sm., *Oscillaria nigroviridis* Thwaites and *Anabaena* sp. were abundant along the marginal portion of the marsh. Later on, they dwindled and, about the end of October, 1949, were very scarce. The dominant member in this community was *Cocconeis littoralis*. In November, 1949, these forms gave place to *Pleurosigma salinarum* Grun. *Amphiprora paludosa* W. Sm. var. *subsalina* Cleve and *Gyrosigma balticum* (Ehr.) Rabh. These forms were dominant from November, 1949 to February, 1950.

The following forms were present in a subdominant condition: *Cocconeis placentula* Ehr. var. *euglypta* (Ehr.) Cleve, *Mastogloia dolosa* Venkataraman, *Pleurosigma angulatum* (Queckett) W. Sm., *Diploneis interrupta* (Kütz.) Cleve, *Tropiodoneis lepidoptera* (Greg.) Cleve, *Amphora coffeaeformis* Ag., *Bacillaria paradoxa* Gmelin, *Nitzschia sigma* W. Sm. var. *indica* Karsten, *N. obtusa* W. Sm. var. *scalpelliformis* Grun., *Gomphosphaeria aponina* Kütz., *Spirulina subtillissima* Kütz., *Phormidium tenue* (Menegh.) Gom. and *Lyngbya* spp.

Epiphytic on Halophila and Cymodocea:

The epiphytes flourished from May to July, 1949. In August, 1949, the host plants were overgrown with *Polysiphonia* and the

epiphytic Diatoms and Blue-green algae disappeared from them. In November, 1949, the *Polysiphonia* community disappeared and the Diatoms and the Blue-green algae community came up once again and covered the host plants. But *Polysiphonia* came up once more and became established on the plants of *Halophila* and *Cymodocea* in February, 1950, and the Diatoms and Blue-green algae community disappeared once again from their host plants.

List of algae growing in the marsh:

1. *Enteromorpha compressa* (Linn.) Grev. var. *lingulata* (J. Ag.) Hauck.
2. *E. prolifera* Ag. var. *tubulosa* (Kütz.) Reinbold
3. *Chaetomorpha littorea* Harv.
4. *C. tortuosa* Kütz.
5. *Rhizoclonium Kerneri* Stockm.
6. *Cladophora* sp.
7. *Endoderma viride* (Reinke) Lagerh.
8. *Lycmophora abbreviata* Ag.
9. *Tabellaria fenestrata* (Lyngbye) Kütz.
10. *Cocconeis placentula* Ehr. var. *euglypta* (Ehr.) Cleve
11. *C. littoralis* Subrahmanyan
12. *Achnanthes brevipes* Ag. var. *intermedia* (Kütz.) Cleve
13. *Mastogloia dolosa* Venkataraman
14. *Diploneis interrupta* Kütz.
15. *Pleurosigma salinarum* Grun.
16. *P. angulatum* (Queckett) W. Sm.
17. *Gyrosigma balticum* (Ehr.) Rabh.
18. *Amphiprora paludosa* W. Sm. var. *subsalina* Cleve
19. *Tropiodoneis lepidoptera* (Greg.) Cleve
20. *Amphora coffeaeformis* Ag.
21. *Bacillaria paradoxa* Gmelin
22. *Nitzschia sigma* (Kütz.) W. Sm. var. *indica* Karsten
23. *N. closterium* (Ehr.) W. Sm.
24. *N. obtusa* W. Sm. var. *scalpelliformis* Grun.
25. *Rosenvingea intricata* Boergs.

26. *Hypnea valentiae* (Turn.) Mont.
27. *Gracilaria confervoides* (Linn.) Grev.
28. *Spyridia filamentosa* (Wulf.) Harv.
29. *Polysiphonia platycarpa* Boergs.
30. *Acanthophora spicifera* (Vahl.) Boergs.
31. *Gomphosphaeria aponina* Kütz.
32. *Spirulina subtillissima* Kütz.
33. *Oscillaria nigro-viridis* Thwaites
34. *Phormidium tenue* (Menegh.) Gom.
35. *Lyngbya Gardneri* (Setchell et Gardner) Geitler
36. *Lyngbya* sp.
37. *Anabaena* sp.

Discussion

The algal flora of the marsh in relation to the salinity of the water:

Six algal communities were distinguished in the marsh during the year, (1) *Chaetomorpha—Gracilaria* community, (2) *Acanthophora-Hypnea* community, (3) *Polysiphonia* community, (4) *Rosenvingea* community, (5) *Enteromorpha—Cladophora* community and (6) the Diatoms—Blue-green algae community. Of these six communities, the *Chaetomorpha-Gracilaria* community and the *Acanthophora-Hypnea* community were growing in the marsh all through the year and were unaffected in any way by the changes in the salinity of the water in the marsh. The algae belonging to these communities were able to adjust themselves to a high salinity on the one hand (4·2%) and to comparatively freshwater conditions (0·25%) on the other. The *Polysiphonia* community was flourishing very well between July and October, 1949. It was also reproducing freely. During this period, the salinity of the water ranged from 1·8% to 2·8%. When the marsh was flooded during the North-East monsoon rains (November and December, 1949), when the salinity became very low, the alga disappeared from its old positions, but came up again in March, 1950, and was flourishing in the locality till the end of this investigation (May, 1950). During the latter period, the salinity of the water in the marsh was very high (4·1%). The alga was quite sterile during this period. Thus it would appear, that this alga, while it grows within

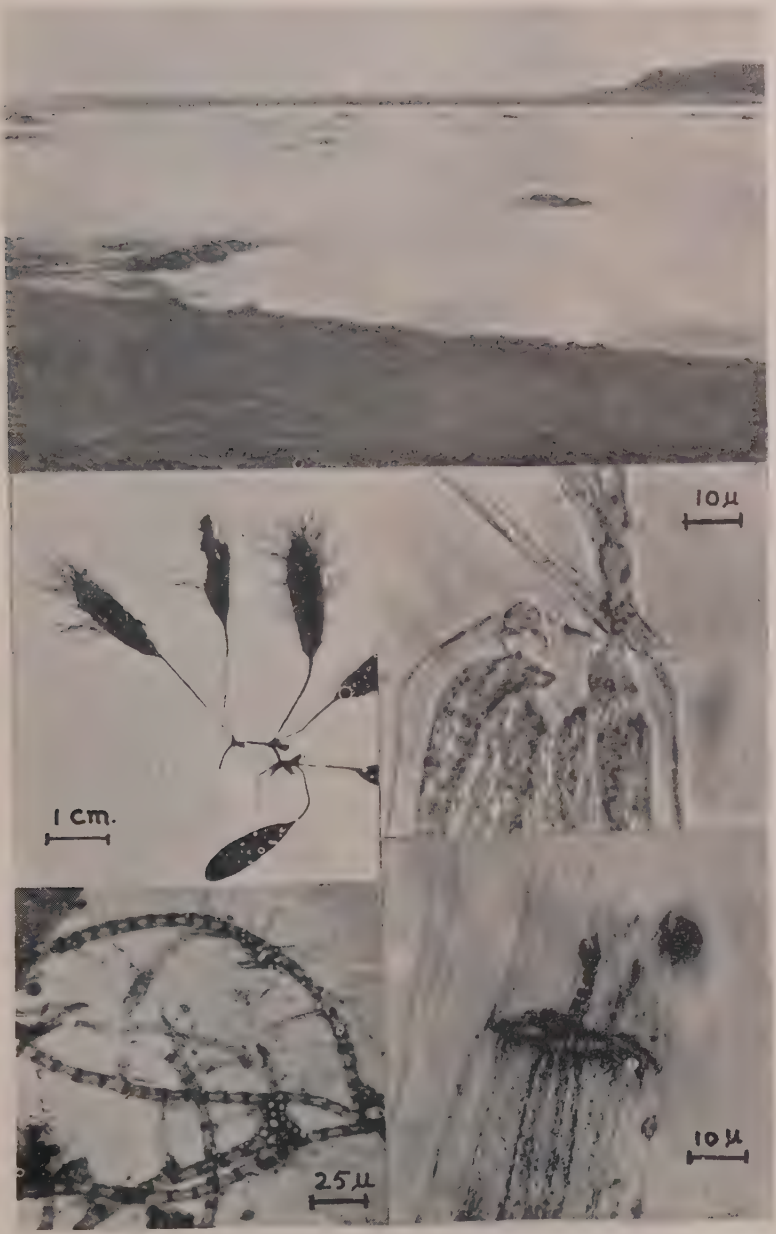


Fig. 1. A view of the salt marsh at the rivermouth of Adyar. Fig 2. *Polysiphonia platycarpa* on *Halophila ovalis*. Fig. 3. *Polysiphonia platycarpa*, showing regeneration from a pericentral cell. Fig. 4. *Spyridia filamentosa*, showing secondary rhizoids. Fig. 5. *Polysiphonia platycarpa*, showing regeneration from a central cell.

a fairly wide range of salinity, viz., 1·8% to 4·1%, it forms reproductive structures only within a comparatively narrow range of salinity, viz., 1·8% to 2·8%.

The *Rosenvingea* community flourished between May and June, 1949, and again between November, 1949, and February, 1950. In the first period, the salinity of the water was very low (0·25% to 1·8%), while in the second, it was high (1·8% to 3·8%). Reproductive stages occurred during the period of high salinity.

The *Enteromorpha—Cladophora* community and the Diatoms —Blue-green algae community occurred from July, 1949, to February, 1950, during which period, the salinity ranged from 1·8% to 3·8%. The maximum development of these communities, however, was in October, 1949, when the salinity ranged from 2·3% to 2·5%.

Seasonal succession in the algal flora of the marsh :

In May, 1949, the algal communities present were the *Chaetomorpha-Gracilaria* community, the *Acanthophora-Hypnea* community and the *Polysiphonia* community. Of these, the first two continued to exist in the marsh throughout the year. The *Polysiphonia* community, however, dwindled in June, but reappeared in July, 1949, and flourished till October. In November, the *Enteromorpha-Cladophora* community became dominant and the *Polysiphonia* community dwindled in the marsh. In March, 1950, the *Enteromorpha-Cladophora* community disappeared and its place was taken up once again by the *Polysiphonia* community. Thus one could recognise a *Polysiphonia* period from July to October, 1949, and an *Enteromorpha-Cladophora* period from November, 1949, to February, 1950. In March, 1950, a second *Polysiphonia* period starts and continues till May, 1950.

A certain kind of succession was observed in the epiphytic algae growing on *Halophila ovalis* and *Cymodocea isoetifolia*. This epiphytic flora consisted of two communities, the Diatoms and Blue-green algae community and the *Polysiphonia* community. In June and July, 1949, the epiphytic flora consisted mainly of the Diatoms and the Blue-green algae. In August, *Polysiphonia* developed extensively and the Diatoms and the Blue-green algae disappeared. Between November, 1949, and February, 1950, when *Polysiphonia* was absent, the Diatoms and the Blue-green algae reappeared and established themselves once again. In March, 1950,

Polysiphonia came up again and completely ousted the Diatoms and Blue-green algae. The succession of these communities is represented graphically in figure 16.

Origin of the algal flora of the marsh :

An examination of the list of forms present in the marsh shows that all the algae growing in the locality, with the exception of a few Diatoms, are essentially marine in occurrence. These algae grow commonly in the sea at places like Pamban, Tuticorin etc., far away from Madras. Detached portions of marine algae like *Sargassum, Turbinaria, Hormophysa, Ulva reticulata* etc., are often seen stranded on the beach at Madras. These algae do not grow anywhere near Madras and so are evidently brought from the above mentioned places along the sea. Fragments of the algae found in the marsh must have been brought along the sea during the monsoon.

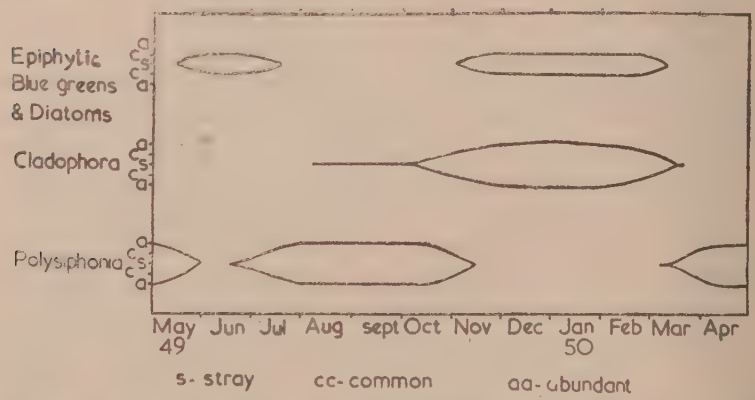


Fig. 16. Seasonal occurrence of the different algal communities in the marsh.

Some of these algae must have found their way into the rivermouth and from there into the marsh. All the forms that have been frequently washed ashore at Madras have not succeeded in establishing themselves in the marsh. The salinity and other conditions of the marsh are such that many of the forms which enter the marsh find them unfavourable for their growth and so gradually perish. Some of the forms were evidently able to adjust themselves to the lower salinity and other conditions of the marsh and so have established themselves in the locality. Some of the forms, like *Polysiphonia platycarpa,* seem to have adapted themselves very successfully to

the conditions of the marsh and are able to reproduce freely, both sexually and asexually. Some other forms, though generally sterile, may occasionally show some reproductive phase, such as cystocarp formation in *Gracilaria,* tetraspore formation in *Acanthophora* and *Spyridia,* and the formation of plurilocular sporangia in *Rosenvingea.* Owing to the rarity of sexual and asexual reproduction in these forms, vegetative propagation by means of fragments of the thallus is commonly met with. Even in the case of *Polysiphonia* which produces both carpospores and tetraspores in plenty, vegetative propagation is more common. In certain other forms like *Hypnea,* though there is abundant vegetative growth, reproductive stages are not met with and the propagation of these forms is purely by fragmentation.

ACKNOWLEDGEMENTS.

The writer wishes to express his deep sense of gratitude to Prof. M.O.P. Iyengar, for suggesting the problem and for his constant and valuable guidance throughout the course of this investigation.

LITERATURE CITED

Anand, P. L. (1940) *Marine algae from Karachi,* Part I—*Chlorophyceae,* p. 52. The University of the Punjab, Lahore.

—— (1943) *Marine algae from Karachi,* Part II—*Rhodophyceae,* pp. 70, The University of the Punjab, Lahore.

Boergesen, F. (1930) Some Indian green and brown algae, especially from the shores of the Presidency of Bombay —I. *J. Indian bot. Soc.,* 9: 151-74.

—— (1932) Some Indian green and brown algae, especially from the shores of the Presidency of Bombay— II. *Ibid.,* 11: 51-70.

—— (1933) Some Indian green and brown algae, especially from the shores of the Presidency of Bombay— III. *Ibid.,* 12: 1-16.

—— (1937) Contributions to a South Indian marine algal flora—I. *Ibid.,* 16: 1-57.

—— (1937) Contributions to a South Indian marine algal flora—II. *Ibid.,* 16: 311-57.

—— (1938) Contributions to a South Indian marine algal flora—III. *Ibid.*, 17: 205-42.

Carter, N. (1932) A study of the algal vegetation of two salt marshes—I. *J. Ecol.* 20: 341-70.

—— (1933) A study of the algal vegetation of two salt marshes—II. *Ibid.*, 21: 128-208.

Chapman, V. J. (1941) *An introduction to the study of the algae,* pp. 387. Cambridge University Press, Cambridge.

Cleve, P. T. (1894) Synopsis of Naviculoid Diatoms, Part 1. *Kongl. Sv. Vet.-Akad. Handl.,* 26 (Suppl.): 1-194.

—— (1895) Synopsis of Naviculoid Diatoms, Part 2. *Ibid.,* 27: (Suppl.). 1-219

Collins, F. S. (1909) *The green algae of North America, Tufts College Studies* 2: 79-480. Tufts College Press, Mass.

Geitler, L. (1932) Cyanophyceae, in Rabenhorst's *Kryptogamenflora,* 16: 1-1196. Akademische Verlagsgesellschaft, Leipzig.

Hustedt, Fr. (1930) Bacillariophyta, in A. Pascher's *Süsswasserflora Mitteleuropas,* 10: 1-466. Gustav Fischer, Jena.

—— (1930, 31-2) Die Kieselalgen, in Rabenhorst's *Kryptogamenflora,* 7: Teil 1, 1-920; Teil 2, 1-576. Akademische Verlagsgesellschaft, Leipzig.

Iyengar, M. O. P. & Venkataraman, G. (1951) The ecology and seasonal succession of the algal flora of the river Cooum at Madras, with special reference to the Diatomaceae. *J. Madras Univ.,* B, 21: 140-192.

Martin, M. T. (1934) Regeneration in *Polysiphonia nigrescens* Grev. *J. Bot.,* 72: 241-43.

Newton, L. B. (1931) *A handbook of the British seaweeds,* pp. 478. British Museum (Natural History), London.

Srinivasan, K. S. (1946) Ecology and seasonal succession of the marine algae at Mahabalipuram, near Madras. *M. O. P. Iyengar Comm. Vol., J. Indian bot. Soc.,* 267-278.

Subrahmanyan, R. (1946) A systematic account of the marine plankton Diatoms of the Madras coast. *Proc. Indian Acad. Sci.* 24: 85-197.

J. Madras, Univ., B, XXIV, No. 2, pages 179-182

Heterocyclic Compounds, Part III * Synthesis of Some Bromo-Quinazolones

BY

M. R. SUBBARAM

(*University of Madras, Madras*-25)

(Received for publication, April 26, 1954)

ABSTRACT

The synthesis of 2-methyl-3-aryl-4-quinazolones with nuclear bromine substituents is reported.

INTRODUCTION

Bogert and Hand (1906) reported the formation of 2-methyl-6-bromoquinazolone by the action of ammonia on 6-bromoacetanthranil. Using aniline they obtained 3-phenyl-6-bromo-2-methyl-4-quinazolone. Grimmel, Guenther and Morgan (1946) obtained 6-chloro-2-methyl-3-phenyl-4-quinazolone by the action of phosphorous trichloride on a mixture of 5-chloro-N-acetylanthranilic acid and aniline. In the present investigation bromo-acetylanthranilic acids were condensed with aromatic amines to give the 4-quinazolones. The yields of the quinazolone derivatives vary from 60 to 80% based on the crude product and 55 to 70% on the pure product.

EXPERIMENTAL

All condensations were carried out according to the method detailed in Part II of this series. Molar proportions of the reactants were used.

2-Methyl-3-(o-toluyl)-6-bromo-4-quinazolone : —

5-Bromo-N-acetyl-anthranilic acid (Bogert and Hand, 1905) and o-toluidine gave the quinazolone (needles) m.p. 139-141°.

* Part II published in the Proceedings of the Indian Academy of Sciences. 40A: 22 (1954).

This compound has been prepared before by Bogert and Hand (1906) by a different procedure and they record its melting point as 137-138°.

$C_{16}H_{13}ON_2Br$: Calculated— N, 8·51% Found 8·27%

2-*Methyl*-3- (*m-toluyl*)-6-*bromo*-4-*quinazolone* : —

N-acetyl-5-bromo-anthranilic acid (2·6 g.) and m-toluidine (1·0 g.) gave 2·4 g. of the quinazolone (from alcohol), m.p. 158-160°.

$C_{16}H_{13}ON_2Br$: Calculated— N, 8·51% Found 8·50%

2-*Methyl*-3- (*o-anisyl*)-6-*bromo*-4-*quinazolone* : —

o-Anisidine (1·2 g.) and N-acetyl-5-bromo-anthranilic acid (2·6 g.) gave 1·8 g. of the quinazolone (from alcohol), m.p. 174-176°.

$C_{16}H_{13}O_2N_2Br$: Calculated— N, 8·11%, Found 8·39%

2-*Methyl*-3- (*o-phenetyl*)-6-*bromo*-4-*quinazolone* : —

o-Phenetidine (1·4 g) and N-acetyl-5-bromo-anthranilic acid (2·6 g.) gave 1·8 g. of the quinazolone (from acetone) m.p. 136-138°.

$C_{17}H_{15}O_2N_2Br$: Calculated— N, 7·80% Found 7·68%

2-*Methyl*-3- (2'-*methyl*-5'-*chlorophenyl*)-6-*bromo*-4-*quinozolone* : —

2-Methyl-5-chloro-aniline (1·4 g.) and N-acetyl-5-bromo-anthranilic acid (2.6 g.) gave 2·1 g. of the quinazolone (from acetone), m.p. 154-156°.

$C_{16}H_{12}ON_2ClBr$: Calculated— N, 7·74% Found 7·86%

2-*Methyl*-3- (*o-toluyl*)-6 : 8-*dibromo*-4-*quinazolone* : —

N-acetyl-3: 5-dibromo-anthranilic acid (Wheeler and Oates, 1910) (3·4 g.) and o-toluidine (1·0 g.) gave 2·1 g. of the quinazolone (from acetone), m.p. 188-190°.

$C_{16}H_{12}ON_2Br_2$: Calculated— N, 6·86% Found 6·76%

2-Methyl-3-(m-toluyl)-6 : 8-dibromo-4-quinazolone :—

N-acetyl-3 : 5-dibromo-anthranilic acid (3·4 g.) and m-toluidine (1·0 g.) gave 2·9 g. of the quinazolone (from acetone), m.p. 208-210°.

$C_{16}H_{12}ON_2Br_2$: Calculated—N, 6·86% Found 6·96%

2-Methyl-3-(p-toluyl)-6 : 8-dibromo-4-quinazolone :—

p-Toluidine (1·0 g.) and N-acetyl-3 : 5-dibromo-anthranilic-acid (3·4 g.) gave 2·3 g. of the quinazolone (from acetone), m.p. 172-174°.

$C_{16}H_{12}ON_2Br_2$: Calculated— N, 6·86% Found 6·90%

2-Methyl-3-(o-anisyl)-6 : 8-dibromo-4-quinazolone :—

N-acetyl-3 : 5-dibromo-anthranilic acid (3·4 g.) and o-anisidine (1·2 g.) gave 2·9 g. of the quinazolone (from acetone), m.p. 209-211°.

$C_{16}H_{12}O_2N_2Br_2$: Calculated— N, 6·60%, Found 6·72%

2-Methyl-3-(o-phenetyl)-6: 8-dibromo-4-quinazolone :—

3 : 5-Dibromo-N-acetyl-anthranilic acid (3·4 g.) and o-phenetidine (1.4 g.) gave 3·3 g. of the quinazolone (from acetone), m.p. 182-184°.

$C_{17}H_{14}O_2N_2Br_2$: Calculated— N, 6·42%, Found 6·57%

2-Methyl-3-(p-chlorophenyl)-6 : 8-dibromo-4-quinazolone :—

N-acetyl-3 : 5-dibromo-anthranilic acid (3·4 g.) and p-chloroaniline (1·3 g.) gave 2·8 g. of the quinazolone (from acetone), m.p. 207-209°.

$C_{15}H_9ON_2ClBr_2$: Calculated— N, 6·54%. Found 6·64%

2-Methyl-3-(p-bromophenyl)-6 : 8-dibromo-4-quinazolone : —

p-Bromoaniline (1·7 g.) and N-acetyl-3 : 5-dibromo-anthranilic acid (3·4 g.) gave 3·2 g. of the quinazolone (from acetone), m.p. 224-226°.

$C_{15}H_9ON_2Br_3$: Calculated— N, 5·92% Found 5·87%

ACKNOWLEDGEMENT

I wish to thank Professor K. N. Menon for the guidance received during the course of this work.

REFERENCES

* Bogert, M. T., & Hand, W. F. (1905) 5-Bromo-2-aminobenzoic acid and certain derivatives, *J. Amer. Chem. Soc.*, **27**: 1480.
J. chem. Soc., Abstracts, **90**: 176.

* Bogert, M. T., & Hand, W. F. (1906) Preparation of 6-bromo-4-keto-dihydroquinazolines from 5-bromo-2-aminobenzoic acid and certain of its derivaties. *J. Amer. Chem. Soc.*, **28**: 98.
J. chem. Soc., Abstracts, **90**: 208.

Grimmel, H. W., Guenther, A., & Morgan, J. F. (1946) New synthesis of 4-quinazolones. *J. Amer. chem. Soc.*, **68**: 542.

Wheeler, A. S., & Oates, W. M. (1910) Bromination of anthranilic acid. *J. Amer. chem. Soc.*, **32**: 770.

* Not seen in original.

J. Madras Univ., B, XXIV, No. 2, pages 183-187, 1954

Heterocyclic Compounds, Part IV*
Synthesis of some Iodo-Quinazolones

BY

M. R. SUBBARAM
(*University of Madras, Madras-25*)

(Received for publication, April 26, 1954)

ABSTRACT

The synthesis of 2-methyl-3-aryl-4-quinazolones with nuclear Iodine substituents is reported.

INTRODUCTION

The Niementowski Procedure (1895) for the synthesis of 4-quinazolones is of fairly general application. Endicott and coworkers (1946) obtained 6-chloro-4-quinazolone by the above procedure by heating 5-chloro-anthranilic acid and formamide.

Bogert and Hand (1906) prepared the 6-bromo compound by the condensation of the ammonium salt of 5-bromo-anthranilic acid with formamide. A survey of the literature reveals that Iodo-quinazolones have not been reported and in the present investigation 6-Iodo-4-quinazolone and 6:8-diiodo-4-quinazolone have been synthesised by the Niementowski (1895) procedure.

Grimmel, Guenther and Morgan (1946) reported the synthesis of 6-chloro-2-methyl-3-phenyl-4-quinazolone by the condensation of 5-chloro-N-acetyl-anthranilic acid and aniline in the presence of phosphorus trichloride. Previous work, reported from this laboratory, was concerned with the synthesis of 6-bromo-2-methyl-3-aryl-4-quinazolones, the 6: 8-dibromo-quinazolones and the 6-methyl derivatives. (Subbaram, 1954). In the present communication the results of studies on the synthesis of the 6-Iodo-4-quinazolones with substituents in positions 2 and 3 are presented.

*Part III, in *J. Madras Univ.* B, 24: 179-182.

The yields of the quinazolone derivatives vary from 65-72% based on the crude product and 50-65% on the pure product. The quinazolones formed were mostly coloured and some were also colourless.

Experimental

6-Iodo-4-quinazolone:—

5-Iodo-anthranilic acid (Klemme and Hunter, 1940) 15·2 g., (0·05 mole) and Formamide (22 g., 0·5 mole) were heated in a 50 ml. round bottom flask provided with an air condenser in an oil bath at 120° for thirty minutes. At the end of this time the temperature was raised to 130° and maintained at this temperature for one hour, and maintained at 160° for 2 hours. The reaction product was cooled and treated with 50 ml. of sodium carbonate solution (10%), the solid left behind was filtered off at the pump and dried in vacuo, when 10 g. of a brown coloured quinazolone was obtained. This on recrystallisation from acetone gave reddish-brown leaflets m.p. 270-272°.

$C_8H_5ON_2I$: Calculated- N, 10·29%, Found 10·20%.

6:8-Diiodo-4-quinazolone:—

3:5-Diiodo-anthranilic acid required for this preparation of this compound was obtained by the method of Higgins and Chessick (1951), in good yields.

The crystallised acid (12 g., 0.03 mole) and Formamide (9 g., 0·2 mole) were heated for one hour at 130-140°, for three hours at 160-165° and thirty minutes at 180°. The light tan substance, obtained after the reaction mixture was washed with 50 ml. of 10% sodium carbonate solution, filtered and dried. The product was recrystallised from pyridine. Yield 8 g. long scaly needles, decomposes above 320°.

$C_8H_4ON_2I_2$: Calculated- N, 7·03%, Found 7·39%.

The following condensations were carried out according to the method given in Part II of this series (Subbaram, 1954). The reactants were taken in Molar proportions.

2-Methyl-3-phenyl-6-iodo-4-quinazolone:—

5-Iodo-N-acetylanthranilic acid (Borsche, Weusmann and Fritzsche, 1924) and aniline gave the quinazolone (pale yellow crystals from dilute ethanol), m.p. 151-152°. Yield 1·5 g.

$C_{15}H_{11}ON_2I$: Calculated- N, 7·74%, Found 7·24%.

2-Methyl-3-(o-tolyl)-6-iodo-4-quinazolone:—

N-acetyl-5-iodo-anthranilic acid (3·0 g.) and o-toluidine (1 ml.) gave 2·7 g. of the quinazolone (fine colourless needles from acetone), m.p. 142-144°.

$C_{16}H_{13}ON_2I$: Calculated- N, 7·45%, Found 6·95%.

2-Methyl-3-(m-tolyl)-6-iodo-4-quinazolone:—

m-Toluidine (1 ml.) and N-acetyl-5-iodo-anthranilic acid (3·0 g.) gave 2·5 g. of the quinazolone (colourless needles from acetone), m.p. 179-181°.

$C_{16}H_{13}ON_2I$: Calculated- N, 7·45%, Found 7·35%.

2-Methyl-3-(p-tolyl)-6-iodo-4-quinazolone:—

p-Toluidine (1 g.) and N-acetyl-5-iodo-anthranilic acid (3·0 g.) gave 2·1 g. of the quinazolone (light brown plates from acetone), m.p. 154-155°.

$C_{16}H_{13}ON_2I$: Calculated- N, 7.45%, Found 7.34%.

2-Methyl-3-(o-anisyl)-6-iodo-4-quinazolone:—

N-acetyl-5-iodo-anthranilic acid (3.0 g.) and o-anisidine (1·2 ml.) gave 2·6 g. of the quinazolone (colourless small needles from acetone) m.p. 178-180°.

$C_{16}H_{13}O_2N_2I$: Calculated- N, 7·15%, Found 7·21%.

2-Methyl-3-(p-anisyl)-6-iodo-4-quinazolone:—

N-acetyl-5-iodo-anthranilic acid (3·0 g.) and p-anisidine (1·2 g.) gave 2·5 g. of the quinazolone (light brown needles from acetone), m.p. 165-166°.

$C_{16}H_{13}O_2N_2I$: Calculated- N, 7·15%, Found 7·26%.

2-Methyl-3-(o-phenetyl)-6-iodo-4-quinazolone:—

5-Iodo-N-acetyl-anthranilic acid (3·0 g.) and o-phenetidine (1·4 g.) gave on condensation 3·5 g. of the quinazolone (colourless needles from alcohol), m.p. 144-146°.

$C_{17}H_{15}O_2N_2I$: Calculated- N, 6·90%, Found 6·89%.

2-Methyl-3-(o-nitrophenyl)-6-iodo-4-quinazolone:—

o-Nitroaniline (1·4 g.) and 5-iodo-N-acetyl-anthranilic acid (3·0 g.) gave on condensation 3 g. of the quinazolone (yellowish white plates from acetone), m.p. 214-215°.

$C_{15}H_{10}O_3N_3I$: Calculated- N, 10·31%, Found N, 10·11%.

2-Methyl-3-(m-Nitrophenyl)-6-iodo-4-quinazolone: —

m-Nitroaniline (1·4 g.) and N-acetyl-5-iodo-anthranilic acid (3·0 g.) yielded 3·7 g. of the quinazolone (pale brown plates from acetone), m.p. 230-232°.

$C_{15}H_{10}O_3N_3I$: Calculated- N, 10·31%, Found 10·29%.

2-Methyl-3-(p-nitrophenyl)-6-iodo-4-quinazolone: —

p-Nitroaniline (1·4 g.) and 5-iodo-N-acetyl-anthranilic acid (3·0 g.) on condensation gave 1·8 g. of the quinazolone (pale yellow flubby mass from acetone) m.p. 208-210°.

$C_{15}H_{10}O_3N_3I$: Calculated- N, 10·31%, Found 10·12%.

2-Methyl-3-(p-chlorophenyl)-6-iodo-4-quinazolone: —

5-Iodo-N-acetyl-anthranilic acid (3·0 g.) and p-chloroaniline (1·3 g.) gave 3 g. of the quinazolone (light brown shining crystals from acetone), m.p. 156-157°.

$C_{15}H_{10}ON_2ClI$: Calculated- N, 7·06%, Found 7·25%.

2-Methyl-3-(p-bromophenyl)-6-iodo-4-quinazolone: —

p-Bromoaniline (1·7 g.) and N-acetyl-5-iodo-anthranilic acid (3·0 g.) gave on condensation 3·5 g. of the quinazolone (colourless prisms from alcohol), m.p. 177-179°.

$C_{15}H_{10}ON_2BrI$: Calculated- N, 6·35%, Found 5·94%.

2-Methyl-3-(2'-methyl-5'-chlorophenyl)-6-iodo-4-quinazolone: —

N-acetyl-5-iodo-anthranilic acid (3·0 g.) and 2-methyl-5-chloro-aniline (1·2 ml.) furnished 1·9 g. of the quinazolone (colourless needles from acetone), m.p. 136-138°.

$C_{16}H_{12}ON_2ClI$: Calculated- N, 6·82%, Found 7·00%.

2-Methyl-3-(2':6'-dimethylphenyl)-6-iodo-4-quinazolone: —

2:6-Dimethyl-aniline (1·2 ml) and N-acetyl-5-iodo-anthranilic acid (3·0 g.) gave 2·1 g. of the quinazolone (needles from dilute alcohol), m.p. 152-154°.

$C_{17}H_{15}ON_2I$: Calculated- N, 7·20%, Found 7·19%.

ACKNOWLEDGEMENTS

In conclusion the author wishes to express his sincere thanks to Professor K. N. Menon, for his keen interest in this work and

for valuable guidance, and to the Government of India for the award of a Research Fellowship.

LITERATURE CITED

* Bogert, M. T. & Hand, W. F., (1906) Preparation of 6-bromo-4-keto-dihydroquinazolines from 5-bromo-2-amino-benzoic acid and certain of its derivatives, *J. Amer. chem. Soc.*, **28**: 98. *J. chem. Soc.*, Abstracts, **90**: 208.

Borsche, W., Weusmann, H., & Fritzsche, A., (1924) Unterschungen ueber Isatin und verwandte Verbindungen, VI: ueber 5-Iod-isatin und 5: 5'-diiod-indigo. *Ber. dtsch. chem. Ges.*, **57**: 1774.

Endicott, M. M., Alden, B. W. & Sherrill, M. L. (1946) Quinazoline derivatives, *J. Amer. chem. Soc.*, **68**: 1303.

Grimmel, H. W., Guenther, A., & Morgan, J. F. (1946) New synthesis of 4-quinazolones, *J. Amer. chem. Soc.*, **68**: 542.

* Higgins, R. W., & Chessick, J. C. (1951) Synthesis of 3: 5-diiodophthalic anhydride and 1: 3-diiodoanthraquinone. *J. org. Chem.*, **16**: 243 (C. A., **45**: 8479i).

Klemme, C. J., & Hunter, J. H. (1940) Synthesis of Iodo-hippuric acids I., *J. org. Chem.*, **5**: 232.

v. Niementowski, S., (1895) Synthesen von Chinazolinverbindungen, *J. Prakt. Chem.*, (2) **51**: 564.

Subbaram, M. R. (1954) Heterocyclic compounds, Part II, Synthesis of 4-quinazolones with substituents in the 2 and 3 positions. *Proc. Indian Acad. Sci., A*, **40**: 22.

Subbaram, M. R. (1954) Heterocyclic compounds, Part III, Synthesis of some Bromo-quinazolones. *J. Madras Univ. B.* **24**: 179-82.

*Not seen in original.

J. Madras Univ., B. XXIV, No. 2, pages 189-212, 1954

The Seasonal Variations and the Succession of the Fouling Communities in the Madras Harbour Waters

BY

A. DANIEL

Zoological Research Laboratory, Madras University

(Received for publication, April 29, 1954)

ABSTRACT

The different members of the animal community which settle and foul timber in the area studied are commented on. The most important of the animal community are the barnacles, *Balanus amphitrite variegatus, Balanus amphitrite communis,* and *Balanus tintinnabulum tintinnabulum.*

The number of different species of barnacles along with the other important members of the animal community settling on wooden test panels is recorded from time to time during the year the experiment was performed and their seasonal variations in differernt months noted.

The advantage of a primary film of diatoms and algae for the settling of sedentary organisms is examined.

The succession of different animals of the community settling on the experimental surfaces during the year is noted.

The differences in the results obtained at Stations A, B & C are discussed with reference to ecological conditions.

I. *Introduction.*

It is well known that piles, pillars of piers and structures which are exposed to the action of sea water are subject to rapid fouling by sedentary organisms which settle on the surface. Extensive studies on these organisms have been made by Johnson and Miller (1935), Coe and Allen (1937), Edmondson (1944), Richards and Clapp (1944), Weiss (1948), Allen and Wood (1950), Knight-Jones and Stephenson (1950), and Smith, Williams and Davies

(1950). These studies were carried out in the British, European, American and Australian coasts, but little has been done in tropical waters, especially in the Indian Ocean. A brief account of the growth and breeding of a few sedentary organisms in the Madras harbour (Paul, 1942), and a short note on the fouling organisms in pearl oyster cages in Krusadi island (Kuriyan, 1950) contain all that is known of these organisms. A study of the animals which cause fouling, their seasonal abundance, of their rate of attachment and the order in which they colonise any area will be of value if made in relation to the tropical conditions.

In the course of his studies of the cirripedes of Madras, the author investigated the composition of the animal communities which foul marine structures, the rise and fall in number of the different members of the communities during the different seasons as well as their succession in settling on different surfaces. By exposing test planks of standard size at selected stations inside and outside the Madras harbour and periodically examining them, considerable data was accumulated regarding the sessile organisms which settle on the experimental surfaces. Though the series of experiments are being still continued, the author felt that the data collected during one year may be presented in this paper.

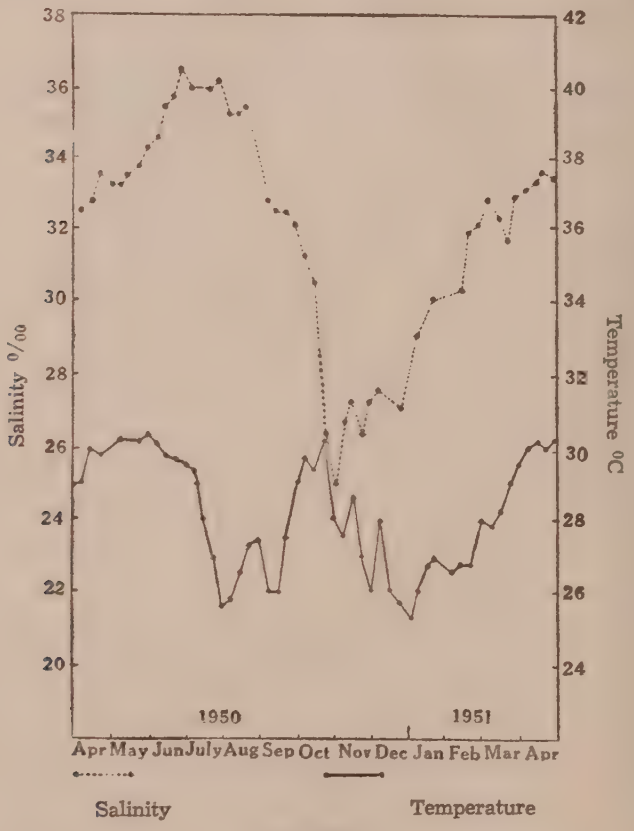
II. *Material and Methods.*

Teak wood planks measuring 8″ × 10″ and one inch thickness were immersed below the low tide mark at three different stations (A, B, and C, vide infra) of the harbour area. At station A within the harbour, the plank was exposed to wave action whereas at station B, being more sheltered, the plank was not exposed to wave action. At station C, which is outside the harbour, the plank was exposed to natural conditions of the open sea. Though the planks were thus subjected to different conditions, the area exposed was equal, being 160 sq. in. The planks were suspended vertically by a pair of stout galvanised copper wires. An iron weight attached at the lower end of the plank ensured the vertical position one foot below the low tide mark, so that during high tide, the test panels were well below four feet from the water level. Owing to the type of suspension these planks were not rigid and offered both sides equally to the settling organisms. These test panels were examined once a week and the attachment of the organisms on both the sides were counted, omitting those that had settled on the edges. An exposure of twenty-eight days ensured an abundant encrustation of

several sessile forms and hence this period of twentyeight days was considered sufficient for purposes of calculation, as was followed by previous workers (Weiss, 1948; and Allen and Wood, 1950). After this period, owing to crowding, the rate of attachment of fresh forms drops and hence exposure for longer periods will not give a true idea of the abundance of the settling organisms in the area. Therefore, while one set of fresh panels introduced on a certain date was accumulating the sessile foulers another set of planks was introduced fourteen days afterwards, and every fortnight one set exposed for twentyeight days was removed and a fresh set was substituted in its place. By this procedure, the number of different species colonising the area during the different parts of the year was noted. Weekly examinations of the test planks, helped an accurate census to be taken right through the year and the variations in the number of different settlers, during the different seasons of the year were studied.

It was found that the different species of sedentary organisms do not attach on separate panels but compete with each other for attachment, food and growth space on the same surface. Owing to this competition some of the early forms drop out and are replaced by later forms, some of the earlier forms offering favourable conditions for their establishment. Thus a particular community dominates at a particular time depending upon the length of time the panel has been under water. To study this succession of the communities a separate series of planks were suspended one foot below the low tide mark, without scraping off the settled organisms for three and six monthly periods. The total number of fouling organisms such as barnacles, polychaetes, etc., were counted. Colonial organisms forming discrete groups of individuals such as erect and encrusting polyzoans were enumerated as individual colonies. In the case of hydroids, tunicates and such colonial forms which spread over large areas, the percentage of the area of the collecting surface was recorded and in the case of diatoms one square centimetre on either side of the collecting planks was scraped off and counted under the binocular microscope. Temperature and salinity observations were made every week (Graph, 1). The temperature of the surface water was read with a centigrade thermometer at 9 A.M. and 5 P.M., the average being recorded as the day's temperature. Salinity was determined by Mohr's method of titration of chlorides using silver nitrate.

Madras (Latitude 13°N and longitude 80°E) is situated on the eastern coast of South India and has a tropical climate, with an annual range of surface water temperature of about 6° C. from a low temperature of 25° C., in January and July and a high tem-



GRAPH I.

Weekly Temperature and salinity records of Madras inshore waters made at the Royapuram beach (April 1950 April 1951.

perature of 13° C., in April and October. The three stations where the samples were collected over a period of a year were chosen to represent ecological distinct habitats and are as follows:

Station A: The first exposure site was located within the main harbour which has an area of 200 acres roughly. As shown in Fig. 1. (St. A.) it lies at the eastern extremity of the new north quay

which juts out from the northwestern corner of the west quay and is 40 yards away from the entrance of the harbour. This site is separated from the ocean by built-in concrete breakwaters, and is subjected to maximum wave action inside the harbour owing to

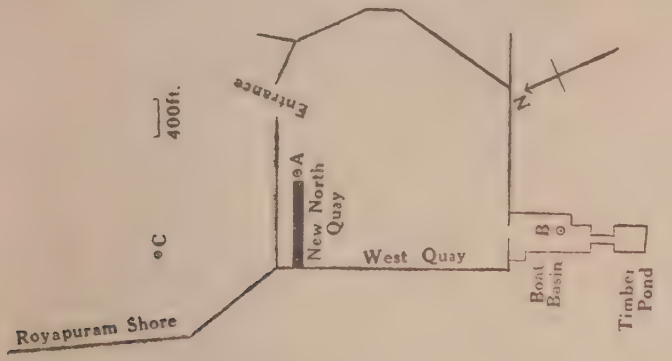


Fig. 1.

Plan of the Madras harbour and Royapuram shore showing the three exposure sites A, B and C.

its close proximity to the entrance. The tide flows rapidly in and out of the main harbour through this site and hence this may be considered to be free from the accumulation of dirt and impurities of the harbour as there is free exchange of water from the open sea into the harbour and vice versa. The water ranges in depth from twentyeight feet at low tide to thirtyone feet at high tide. As the tide flows in east-western direction, the water from the boat basin has to flow out only through this site. It may be concluded from these observations that ocean water and the boat basin water are brought to this site alternatively.

Station B: The second exposure site (Fig. 1. St. B.) was at the south buoy of the boat basin, which has an area of only 52,000 sq. ft. The entire boat basin where the site was located is in communication with the main harbour only by a very narrow entrance and as such is almost free from the action of waves. As this site is situated far away from the entrance of the harbour by a distance of nearly 500 yards, there is a very little exchange of pure water from the open sea as during the tidal inflow only water from the main harbour is forced in. This water is stagnant and hence impure and considerably polluted. As boats are constantly scraped

off here, very near to this site a large number of larvae of sedentary organisms are released into this basin. The depth at this place is twentythree feet at low tide and twentyfive feet at high tide.

Station C: The third exposure site (Fig. 1 St. C.) was in the open sea, at a distance of 120 feet from the Royapuram shore, which is towards the north of the harbour. This shore is rocky and exposures were made from the western side of an old ship which had run aground. The depth at this place is twenty feet at low tide. As sewage flows out into the sea about 800 yards away from this site, this site offers an abundant fauna of the sedentary animal community.

III. The Fouling Organisms.

From the exposed test planks the following organisms were collected and identified in the laboratory:

Diatoms: *Biddulphia* sp., *Rhizosolenia* sp., *Chaetoceros* sp., *Thallasiothrix* sp., *Bacteriastrum* sp., *Coscinodiscus* sp., *Ditylium* sp., *Bellerochea* sp., *Asterionella* sp.

Algae: *Trichodesmium* sp., *Ulothrix flacca, Champia parvula, Centroceras clamlatum, Ceramium sp.*

Protozoa: *Vorticella* sp.

Porifera: Sponge.

Coelenterata: *Laomedia spinulosa* Bate, *Campanularia* sp.

Polyzoa: *Crisia* sp., *Membranipora* sp., *Bowerbankia* sp.

Annelida: *Pomatoleios crosslandi* pixell, *Hydroides norvegica* Gunnerus, *Hydroides lunulifera, Serpula vermucularis* L. *Dasychone cingulatus, Loimia medusa* savigny, *Polydora* sp.

Mollusca: *Teredo* sp., *Modiolus striatulus, Modiolus undulatus, Modiolus metcalfei, Ostrea madrasensis, Mytilus viridis, Patella* sp., *Libitina* sp., *Avicula* sp.

Tunicata: *Polycarpa* sp., *Diandrocarpa brackenhielmi, Herdmania* sp., *Botryllus* sp.

Cirripedia: *Balanus tintinnabulum tintinnabulum, Balanus amphitrite communis, Balanus amphitrite variegatus, Balanus amphitrite venustus, Balanus eburneus, Balanus amaryllis* f. *euamaryllis, Tetraclita purpurascens, Chthamalus stellatus stellatus, Lepas anatifera indica, Lepas anserifera.*

Amphipoda: *Stenothoe gallensis* Walker, *Elasmopus pectenicrus* (Bate), *Protogeton* sp.

Isopoda: *Sphaeroma vastator Sp.* Bate.

Arachnida: Pycnogonids.

A total of 57 different species of fouling organisms are recorded. Associated with these fouling organisms were many other members of the animal community finding shelter and foothold.

IV. *The Seasonal Variations:*

Diatoms:

Since care had to be taken to avoid damage to the experimental panels the collection of diatoms was confined to only small portions of the experimental planks. Hence, the diatoms enumerated are comparatively small in number. The most abundant and frequently inhabiting diatoms are *Chaetoceros* sp., *Rhizosolenia* sp., and *Biddulphia* sp. *Chaetoceros* sp., developed in the panels from September to January with a maximum in November *Rhizosolenia* sp., and *Biddulphia* sp., were very common from February to May with their maximum in March and April respectively. *Thallosiothrix* sp., *Ditylium* sp., and *Asterionella* sp., occurred during October to December and *Bellerochea* sp., in March and April.

It is curious to note that in June, July and August the diatoms were not so abundant as in the other months. This is probably due to the fact that during those months the salinity was at its maximum. It was also found that the fouling of the monthly panels during these months was less marked, suggesting that subsequent fouling is entirely dependent upon the primary diatom film. Coe and Allen (1937) and Allen and Wood (1950) maintain that diatoms not only contribute to a large part of the growth but also provide food for the animal settlers.

Algae:

Ulothrix flacca, Champia parvula, Centroceras Clamlatum and *Ceramium* sp., were present during March, April and May in the test panels at all the stations. Only *Trichodesmium* sp., occurred in the upper part of the panels at station B and C throughout the year.

Protozoa:

Vorticella sp., occurred in large numbers during February to June at all the three stations but at station B they were comparatively abundant.

Porifera:

A sponge (unidentified) was found to occur in the test panels abundantly during September, October and December only at station C and was found in smaller numbers throughout the year. This was found to attach only to the three and six monthly panels.

Coelenterata:

The hydroid *Laomedia spinulosa* Bate was the most abundant of the Coelenterates which occurred in all the three stations. The first settling of this species was observed at the end of August and it continued to occur in large numbers till the end of March. This hydroid had its peak in January and February. (Graph. 3).

Another hydroid *Campanularia* sp., was observed at station A alone during October to January but these were not in such abundance as the previous hydroid.

Another coelenterate which was met with, are the anemonies which attached only to the three and six monthly panels in March and April, only at station C.

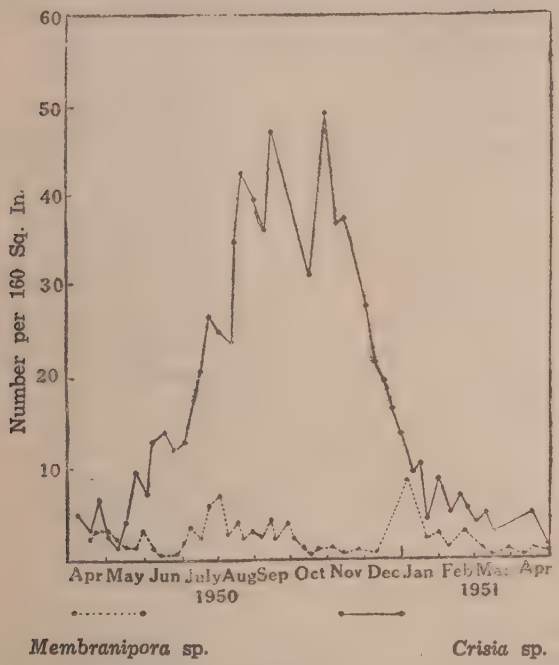
Polyzoans:

The erect polyzoan *Crisia* sp., was found attached only to previously fouled panels—in the later stages in the monthly panels and to three and six monthly panels throughout the year, with a maximum from August to October. They occurred only at stations A and B. (Graph 2). The encrusting polyzoan *Membranipora* sp., in sharp contrast to *Crisia* sp., attached only to freshly immersed planks after the diatoms and the protozoans and the barnacles. These were never met with in large numbers. They occurred from April to September and again reappeared from January to March. (Graph 2). They were never met with one month after immersion since invariably other sedentary organisms settled over it suppressing the further growth of this form which occurred in all the three stations. The other Polyzoan, *Bowerbankia* sp., occurred in all the three stations only in the three and six monthly panels in abundance from August to September.

Annelida:

Seven species of the tube-dwelling Annelid worms occurred on the test panels. Of these *Pomatoleios crosslandi*, *Loimia medusa* and *Polydora* sp., were rare, the former occurring at station B and the latter two at station C. *Hydroides nervegica* and *Serpula ver-*

mucularis were by far the most abundant of the Annelids and constituted a large proportion of the fouling mass coming in next only to the barnacles at stations A and B, having their peak from November-December. (Graph 4). However, at station C it did not occur



GRAPH 2

Weekly attachment of the erect Polyzoan *Crisia* sp. and the encrusting Polyzoan *Membranipora* sp. at Station B April 1950-April 1951.

in such great numbers as at station A and B. *Hydroides lunulifera* occurred at stations A and B during the months of December and January. *Dasychone cingulatas* attached only to 3 and 6 monthly panels in March, April and May.

Mollusca:

The principal organism among the Molluscs which causes a great deal of damage is the borer *Teredo* sp. Although this is of considerable importance in the fouling biology and its presence at stations A and B was definitely established, because it is a boring organism, its seasonal abundance could not be studied. However,

a photograph of the damage caused by *Teredo* sp., to a panel immersed in February 1950 and taken out on June 1951 at station A is given. (Plate, Fig. V.). Another mollusc of importance is *Modiolus striatulus* which occurs at station C right throughout the year, with a peak during June and July and another during February and March. (Graph 5). This mollusc comes next in importance to the barnacle group of the animal community at station C. However, at stations A and B it was present only in small numbers.

Ostrea madrasensis attaches itself only to heavily fouled test panels. It prefers the hard rocks on the sides of the harbour. Nevertheless it attaches to the sides of the barnacles and suppresses their growth. It was observed at stations A and B during the months May to September 1950 and again during March 1951.

Modiolus metcalfei, Modiolus undulatus and *Mytilus viridis* occurred only on the three and six monthly plates at stations A and B, the former two occuring during July to December and the latter though present in the nearby piles throughout the year attached to experimental blocks only during September to November.

Libitina sp., and *Avicula* sp., occurred at Stations A and B in the month of October and were rare. A total number of about 22 specimens were collected during this month. It may be interesting to note that a plank immersed at station A at a depth of about 15 feet had a number of *Avicula* sp., attached to it.

Patella sp., occurred at station C, only on heavily fouled, three and six monthly plates, during the months of June to September and again during January to March.

Tunicates:

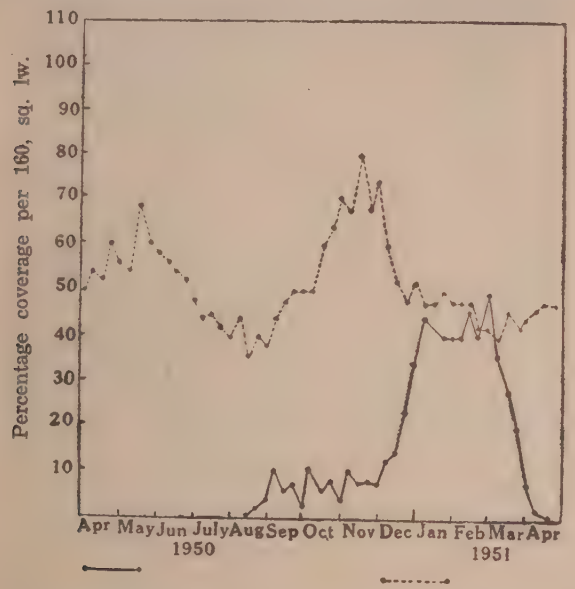
The simple leathery ascidian *Polycarpa* sp., occurred in stations A and B from May to October only to the three and six monthly plates. Only on three occasions was it collected from the monthly plates.

Herdmania sp., was very rare and was obtained from the three and six monthly panels at station A during September to December.

Botryllus sp., was also very rare and was obtained from the three and six monthly panels at station B during April and May.

Most frequently in the heavily fouled plates at stations A and B the compound Ascidian *Diandrocarpa brackenhielmi* was found

spreading over a large area. It occurred throughout the year, and occurred on the monthly panels only after a fornight of immersion and came next in abundance to the annelids, *Hydroides norvegica* and *Serpula vermucularis.*



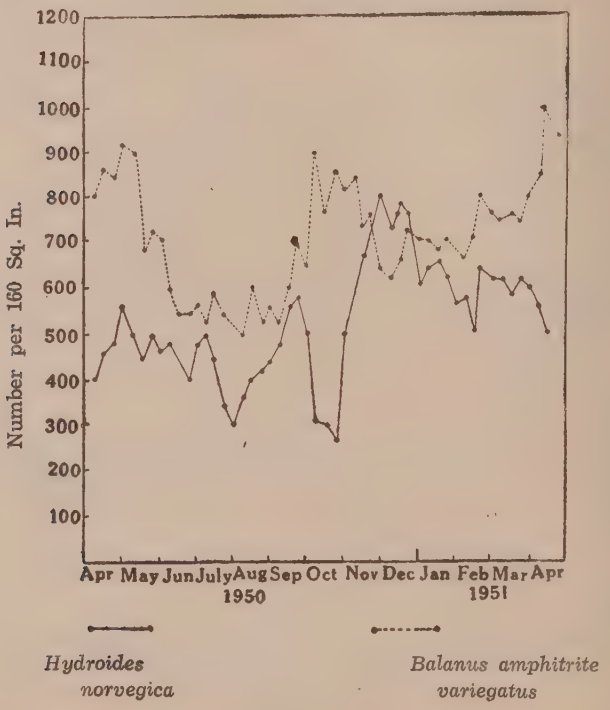
GRAPH 3

Weekly attachment of the Compoused Ascidian *Diandrocarpa brackenhielmi* and the Coelenterate *Laomedia spinulosa* at Station B. (April 1950-April 1951).

Cirripedia:

The barnacles were invariably the dominant organisms on all surfaces exposed for one month at all the stations. Of the barnacles enumerated in Table I, *Balanus amphitrite veriegatus* plays an important part in the fouling complex at stations A and B; occuring invariably in all seasons of the year, (Graph 4), whereas *Balanus tintinnabulum tintinnabulum* and *Balanus amphitrite communis* are confined to station C alone (Graph 4). While *Balanus amphitrite communis* occurs right through the year (Graph 5) *Balanus tintinnabulum tintinnabulum* (Graph 5) has two sporadic occurrences during the months of July and August, and December

and January during which months the former registered a minimum occurrence. It is evident from Graph 1 that in July and August and December and January the temperature of the water is the lowest indicating that probably temperature aids in their sporadic occurrence. Another feature of interest is that in spite of the fact

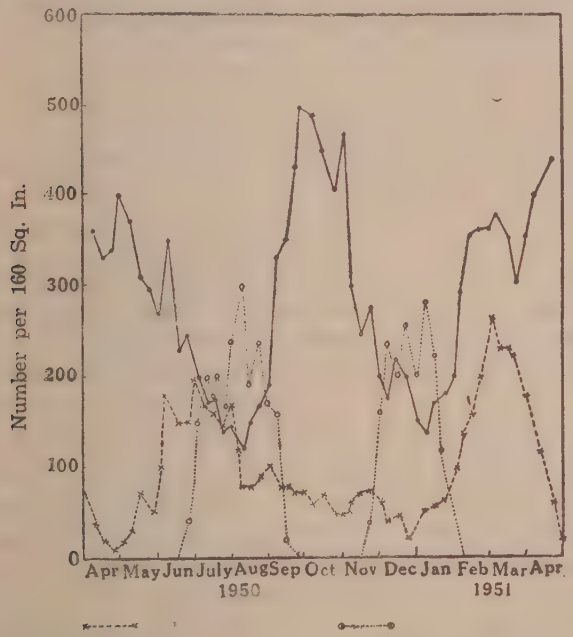


GRAPH 4.

Weekly attachment of the Barnacle *Balanus amphitrite variegatus* and the *Polychaete Hydroides norvegica* at station B. (April 1950-April 1951).

that stations A and C are not far of from each other, *Balanus amphitrite variegatus* occurs on the panels at stations A and B while *Balanus tintinnabulum tintinnabulum* and *Balanus amphitrite communis* occur at station C, where they form the essential components of the fouling complex. It is evident that *Balanus amphitrite variegatus* prefers harbours and still waters. *Chthamalus stellatus stellatus* was seen to occur on hard metal of the stranded ship throughout the year at station C, but as it prefers

to attach to hard substrata, its occurrence on the test panels was rare. However, in the three and six monthly plates it attached to the hard surfaces offered by the other barnacles. The remaining barnacles, *Balanus amphitrite venustus, Balanus eburneus, Balanus amaryllis forma euamaryllis, Tetraclita purpurascens, Lepas anatifera indica* and *Lepas anserifera* although forming a part of



GRAPH 5

Weekly attachment of the Barnacles, Balanus Amphitrite variegatus, Balames tintinnabudum tintinnabulum and the mollusc *Modiolus striatulus* at station C. (April 1950-April 1951).

the fouling community, were negligible in view of the fact that they occurred in small numbers.

Amphipoda:

Of the three species of Amphipods, *Elasmopus pectenicrus* (Bate) alone appeared in large numbers, living upon the organic detritus, and occurred all the year round. But in the month of

January, February and March, the Caprellid, *Protogeton* sp., also appeared in considerable numbers.

Isopoda:

Another major fouling organism was the burrowing isopoda *Sphaeroma vastator* Spence Bate occurring as it does at all stations. Further it was found in abundance throughout the year reaching the maximum numbers during the months of January to March.

Pycnogonids:

Although they occur at stations A and B they are relatively small in number.

V. *The Succession of the Communities*:

The exposure of the monthly plates, at the three different stations reveals the seasonal occurrence of the fouling organisms. The succession of the communities on the test panels, in the three stations is the same whenever the test was made during the year.

(a) *The Succession of the Communities at Stations A & B*:

At the commencement of each experiment when the test panels were immersed at stations A and B under water, the first to attach were the various diatoms, algal spores, and *Vorticella* sp., but no free swimming larvae of the other sedentary organisms attached themselves to the test panels for the first three days. Examination of the block with a hand lens is always necessary for complete accuracy. An equal area of the pillars of piers at station A and the sides of the buoy at station B, was scraped and cleaned as much as possible. It was impossible to rid of the thin primary encrustation. These areas, cleared of all macrofouling organisms, began to show a dense accumulation of the barnacle, *Balanus amphitrite variegatus* and the tubiculous polychaetes, *Hydroides norvegica* and *Serpula vermucularis* within three days, since there was no time lost in preparing the primary film as in the case of the test panels. The free-swimming larvae of the barnacles and the serpulids settled on the test panels only by the end of the third day.

By the end of the first week juvenile barnacles and serpulids appeared in small numbers along with the encrusting polyzoan *Membranipora* sp. Fortnightly plates showed a similar picture but the size and number of all the organisms so far listed increased

(Plate I, Fig. 1). By the end of the third week the number of barnacles and serpulids attaching to the test panels reached their maximum. At this period the erect polyzoan *Crisia* sp., appeared (Plate I, Fig. II).

At the end of a month the plates (Plate I, Panel III) appeared in marked contrast to that at the end of a fortnight as the number of serpulids and barnacles settling on the panels decline while the Polyzoan *Crisia* sp., increases in size and number and many other organisms settle at this period. The other organisms settling are *Bowerbankia* sp., the mollusc *Modiolus metcalfei* and the compound ascidian *Diandrocarpa brackenhielmi* which appeared on the panels at this stage. All these organisms now thrive well and grow rapidly and these organisms offer food and shelter for the amphipods, Isopods and other free-living organisms which grow at the expense of the fouling community.

It is at this stage (i.e.) between the 4th and the 6th week, that maximum fouling organisms are met with on the test panels. Once the compound ascidians settle they spread over the other fouling organisms and limit their growth.

At the end of six weeks the tubiculous serpulids and other foulers are stifled by the spreading over of the compound ascidians, but the barnacles survive even this hindrance by not allowing the ascidians to grow at the entrance to the mantle-chamber and thus successfully compete with the ascidians. By the end of the second month the major organisms forming the fouling complex are the compound ascidians and the barnacles. These two continue to occupy the space competing with each other, the compound ascidian suppressing all the other sedentary organisms and preventing further settlement of barnacles and others. At the end of the third month the ascidians reach their maximum and thereafter gradually fall off, leaving the barnacles alone on the test-panels. (Plate I, Fig. IV). Further exposure resulted in the settlement of only barnacles and no other fouler. The interstices caused by the death and decay of barnacles here and there are occupied by animals like the boring isopod *Sphaeroma vastator*, and other polychaetes.

(b) *The Succession of the Communities at Station C*:

At station C also, test panels immersed in the sea water did not accumulate any visible fouling organism for the first three days,

eventhough to the sides of the ship scraped off, of all macrofouling, *Balanus amphitrite communis* and *Balanus tintinnabulum tintinnabulum* and *Modiolus striatulus* attached in appreciable numbers. The place of the barnacle *Balanus amphitrite variegatus* at Stations A and B is taken over by *Balanus amphitrite communis* and that of the serpulids is taken over by the mollusc *Modiolus striatulus* at station C, and *Balanus tintinnabulum tintinnabulum* is present in addition during July, August, December & January. These organisms settle in large numbers till the end of the third week. The encrusting polyzoan also forms an important organism of the fouling complex at this stage. By the end of the third week the number of barnacles and molluscs attaching to the test panels reached its maximum.

At this stage, the Polyzoan *Bowerbankia* sp., and the mollusc *Patella* sp. appear in large numbers and by the end of the month the sponge settles on the barnacles and completely spreads over the panels. The important settlers at station C at the end of two months are the barnacles, the Mollusc *Modiolus striatulus* and *Patella* sp., and the sponge. Further immersion resulted in the eradication of the sponge and *Patella* sp. Only the barnacles, the Mollusc *Modiolus straitulus* and some algae (unidentified) were present in the three monthly panels.

Discussion:

How far a test panel with its restricted area, can supply data for generalisation regarding fouling in waters on large surfaces, can be doubted. Coe and Allen (1937) suggested that a single surface with an area of 500 Sq. Cm. will obviously offer only an extremely restricted lodging place as compared with the almost limitless variety and extent of surfaces available on the supports for the piers and the adjacent rocky shores. All the organisms present may not necessarily attach themselves to a single plate. However, an examination of the experimental panels and the adjacent piers for more than a year reveal that many of the organisms present in the surrounding water do attach in the experimental plates at some time or other and the data collected are considered sufficient to draw some definite conclusions.

The identity of the main fouling organisms in the tropical waters of Madras is now established. In the area examined the main fouling organisms in the order of dominance are the barnacles

Balanus amphitrite variegatus, Balanus amphitrite communis, and *Balanus tintinnabulum tintinnabulum,* the tubiculous polychaetes *Hydroides nervegica* and *Serpula vermucularis,* the Mollusc *Modiolus striatulus,* the compound ascidian *Diandrocarpa brackenhielmi,* the polyzoans *Crisia* sp., and *Bowerbankia* sp. and the Coelenterate *Laomedia spinulosa* and the free living boring isopod *Sphaeroma vastator.*

While the number of these attaching organisms in the tropical waters of Madras compared to those of temperate and subtropical waters was generally higher than in the temperate and subtropical waters the number of species was by no means larger. A comparison of the fouling organisms of Madras with those of the other parts of the world reveals that the most important component of these settlers are the barnacles, of which *Balanus balanoides, Balanus crenatus, Balanus glandula,* and *Balanus tintinnabulum californicus* are met with in the temperate waters, at California by Coe and Allen 1937; at Lamoine, Maine by Fuller 1946. In the subtropical waters such as Biscayne Bay Florida (Weiss, 1948) Miami Beach (Smith, Williams and Davis 1950) Australia, (Allen and Wood 1950) however, *Balanus improvisus, Balanus eburneus, Balanus trigonus, Balanus amphitrite cirratus* and *B. a. communis* form the chief fauna of the barnacle community, while in the tropical waters such as, as also Madras, *B.a. communis, B. a. variegatus, B. tintinnabulum tintinnabulum* were found attached to the test panels. The tubiculous polychaetes represented by *Hydroides norvegica* and *Serpula vermucularis* and which are met with in large numbers in Madras is not an essential component of these settlers in the temperate and subtropical zones. However, Allen and Wood (1950) report of the occurrence of another species *H. multispinosa* off Australia as a minor settler. Of the molluscs, *Mytilus californicus,* and *Mytilus edulis* are common settlers in the temperate waters (California, Coe and Allen 1937; Laimone, Maine, Fuller, 1946) in the tropical waters however they are replaced by *Modiolus striatulus. Mytilus viridis* also has been recorded from the test panels in Madras. Among the ascidians, while *Didemnum candidum, Botrylloides nigrum, Botryllus planum, Distoma* sp, and *Pyura* sp, are the important settlers in the subtropical waters (Weiss, 1948; Smith; Williams and Davis, 1950; Allen and Wood 1950) only *Diandrocarpa brackenhielmi* was met with in abundance in the tropical waters of Madras. While the occurrence of the

polyzoans, *Bugula* sp, and *Watersipora* sp. is common in the temperate and subtropical waters (Biscayne Bay, Weiss 1948, Miami; Smith William and Davis 1950), it is absent in the tropical waters and are replaced by *Crisia* sp., *Bowerbankia* sp., and *Membranipora* sp. Review of these facts force the conclusion that (i) the overall greater population of foulers may be due to the greater intensity of animal life (vide infra) in the tropical area than in the temperate and subtropical areas. (ii) The presence of tubiculous polychaetes in Madras as against their absence in the temperate waters must be balanced against the greater number of the ascidians *Didemnum candidum, Botrylloides nigrum, Botryllus planum, Distoma* sp. and *Pyura* sp. occurring in Biscayne Bay, Florida, Maine, and east coast of Australia whereas the Madras ascidian *Diandrocarpa brackenhielmi* is not so dominant. (iii) The presence or absence of particular species of barnacles, ascidians, and polyzoans must be due to their general geographical distribution than to any special ecological factors of the tropical or subtropical areas discussed.

The fluctuations in the composition of the fouling communities and the predominance of different groups at different times are of interest. Although the different fouling communities continued to settle in the various test panels throughout the year, they appeared to predominate in definite seasons as for example the diatoms are in abundance from April to May and again from October to March; the coelenterate *Laomedia spinulosa* from August to March; the polyzoans *Crisia* sp. and *Bowerbankia* sp. from August to September; the Annelids *Hydroides norvegica* and *Serpula vermucularis* during November and December; the Mollusc *Modiolus striatulus* having its peak in June and July and February and March and the barnacle *Balanus tintinnabulum tintinnabulum* having two sporadic occurrences during the months of July and August and December and January, the other barnacles *Balanus amphitrite communis* and *Balanus amphitrite variegatus* appearing throughout the year in almost equal numbers. Thus it is seen that consequent on the breeding being continued throughout the year, settling of the different species, on the test panels is not distinguishable into definite periods. Similar observations made by Scheer ('45) at Newport harbour, California where the temperature ranges from 14°C to 19°C and Smith, Williams and Davis ('50) at Miami where the temperature ranges from 16°C to 32°C lend support.

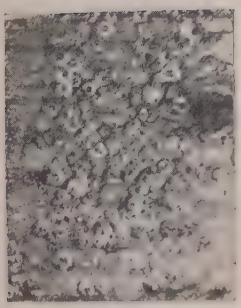


Fig I.

Fig II.

Fig III.

Fig IV.

Fig. V.

The succession of the Communities in Stations A & B inside the harbour.
(For explanation see text)

The basic problem in the development of a sequence of communities in a limited environment is that of distinguishing between seasonal progression and true ecological succession. (Scheer, 1945). Seasonal succession is usually observed in areas where the seasons are well marked and different short lived settlers peculiar to particular seasons, succeeding each other. Ecological succession on the other hand may be observed during a particular season or in areas with no well-marked seasons. This succession involves definite relations between organisms, and is occasioned by factors of the environment, some of the earlier forms being essential for preparing the substratum for the establishment of the later forms and some of the early forms being displaced as the result of interspecific slings. Dealing with these two types of succession, conflicting views have been expressed by Wilson ('26) Shelford ('30); Hewat ('35); McDougal ('43); Scheer ('45); and Smith, Williams and Davis ('50). In Madras however, where the temperature ranges from 25°C to 31°C and therefore there are no sharp well marked seasons there is no seasonal succession of fouling communities. Scheer (1945) working at Newport harbour, California where the temperature range is similar have also found no marked seasonal succession. But ecological succession, is a fact of observation. In Madras the primary film which consists essentially of diatoms is followed by the barnacles and the tubiculous polychaetes and then the polyzoans and next the molluscs followed by the ascidians and finally once again the barnacles which, finally occupy the whole area crowding out all other forms. At the time the barnacles were attaching themselves to a test panel already encrusted with the primary film, a fresh panel was introduced to which the barnacles did not attach themselves. It is evident from the above observation that the primary slime is an essential factor for the attachment of barnacles and serpulids. The fact that the larvae of polyzoans which are capable of attaching themselves to a substratum do not attach on a test panel with the primary slime, and attach only when the barnacles and serpulids have arrived indicate that probably a certain type of roughness of surface is required for anchoring of the larvae. Experiments carried out at every stage of succession reveal the interdependence of one community on the other and that not only the polyzoans but also the Molluscs and ascidians require a certain type of roughness. Once the ascidians settle, they spread over the other fouling organisms and stifle the remaining members of the fouling community. The

barnacles, which are provided with cirri by their constant movement prevent the spreading of the ascidians over the entrance to the mantle chamber and hence their survival, so that in a test panel at this stage the barnacles and the ascidians form the predominant members. On the smooth surface of these ascidians the other larvae are not able to attach themselves since the slippery surface prevent further settlers from attaching. However, when the ascidians fall off leaving a rough surface of the barnacles exposed only the barnacles are capable of settling. Thus the present investigations tend to reveal that in Madras there is a definite ecological succession since invariably the same sequence of events take place irrespective of the season during which it is exposed. A similar sequence was observed by Scheer (1945) at New port harbour where the algal community was followed by the bryozoan community and then the ciona community and next the Styela community and next the Mytilus community and finally the balanus community. Allen and Wood (1950) found that in Australian waters the first to attach were the diatoms and algal spores followed by the serpulids and barnacles and then the ascidians and bryozoans.

The role played by the primary film in the attachment of sedentary organisms to surfaces is a matter on which opinion is much divided. While Angst (1923), and Whedon (1937) consider the presence of a slime film on a surface as prerequisite to the attachment, it is maintained that a primary film is not essential for attachment (Hilen, 1923; Miller and Cupp, 1942; Miller, 1946). However, Zobell (1939), Miller, Rapean and Whedon (1948), Cole and Knight-Jones (1949) hold the view that a primary film may facilitate their attachment. In the light of the above observations it is likely that the failure of the attachment of the free-swimming larvae of the sedentary animal community to freshly immersed test panels is due to the absence of the primary film. Although it is maintained that the primary film consists mainly of bacteria (Zobell, 1939) the present author, while examining the scraped portions of the experimental planks for diatoms and bacteria has found that in Madras the primary film is mainly constituted of diatoms. Similar observations made by Wood (1950) lend support. The fact that during the months of June, July and August when the diatoms were at the minimum and a corresponding fall in the fouling complex strengthens such a view.

A comparison of the fouling records obtained at stations A, B and C reveals that while there is no significant difference in the species collected at stations A and B, which are inside the Madras harbour, there is a difference in the species collected at C which is outside the harbour in the open sea. The relative numbers of the organisms present occur in greater abundance at station B rather than in A and C and must be accounted for only from their peculiar ecology. At station B which is situated far within the harbour waters, the boats are scraped off, the crushed organisms may foul the water and facilitate the settling of fouling organisms. At station C on the other hand which is situated outside the harbour the water is fresh and clear, and fouling is not so pronounced. At station A which is just within the harbour, exposed to tidal currents of 2-3 knots and also accessible to the polluted water when the tide flows out of the boat basin fouling is more pronounced than outside the harbour but less than B. Since it is known that factors like, periodic exposure at each tide to bay water which is little mixed with ocean water, a body of water surrounded by concrete bulk-heads and wharf-pilings, tidal currents of 2-3 knots and moderately polluted water help in large scale fouling (Weiss, 1948) stations B which has all these factors fouling is much pronounced.

It appears that all the factors, enumerated by Weiss (1948), which play an important part in fouling in the temperate zones, play an equal part in the tropical waters. However, it must be remembered that due to the relative high temperature and consequent high metabolic activities resulting in the rapid rate of growth and the attainment of sexual maturity at a surprisingly early age, (Paul, '42); availability of sufficient planktonic food throughout all the seasons of the year (Marshall, 1933); the acceleration of the hatching of the eggs and the quicker development of the larvae (Delsman, 1929); and the constant settling down of generations of organisms with production of several offsprings in a year, fouling in the tropics is much more pronounced.

Acknowledgement

This work was carried out at the University Zoological Research Laboratory, Madras. I am thankful to Dr. C. P. Gnanamuthu, M.A., D.Sc., for suggesting this problem and outlining the work, for help and guidance throughout the course of this investigation.

To the harbour authorities my thanks are due for giving me all facilities during my investigation in the harbour area and lastly I thank the Syndicate of the University of Madras for awarding me a studentship during the tenure of which this work was carried out. This paper represents part of the thesis approved for the M.Sc. degree of the Madras University.

REFERENCES

Allen, F. E., & Wood, F. (1950) Investigations in Underwater Fouling. *Austr. J. Mar. & Fresh Water Res.* 1: 92-105.

*Angst, E.C. (1923) *The Fouling of Ships bottoms by Bacteria.* Bur. Const. Repair. Navy Dept. U.S.A.

Atwood, W. G., & Johnson, A. A. (1924) *Marine structures, their deterioration and preservation.* *National Research Council Report.* Washington. 1-525 pp.

Coe, W. R., & Allen, W. E. (1937) Growth of sedentary marine organisms on experimental blocks and plates for nine successive years at pier of the Scripps Instn. of Oceanography. *Bull. Scripp. Inst. Ocean. Tech. Sr.* 4: 101-36.

Cole, H. A., & Knight-Jones, E. W. (1949) The settling behaviour of larvae of the European flat oyster, *Ostrea edulis* L., and its influence on methods of cultivation and spot collection. *Fish. Invest.*. Ser. 11, 17: 1-39.

Delsman, H.C. (1929) The study of Pelagic Fish-eggs. *Proc. 4th Pacific Sci. Cong.*, Java; pp. 36-38.

Edmondson, C.H. (1944) Incidednce of fouling in Pearl Harbour. *Occas Papers, Bernice P. Bishop Museum* 18: 1-32.

Erlanson, E. W. (1936) A preliminary survey of marine boring organisms in Cochin harbour. *Curr. Sci.* 4: 726-732.

Fuller, J.L. (1946) Season of attachment and growth of sedentary marine organisms at Lamoine, Maine. *Ecology,* 27: 150-158.

Graham, H. W., & Helen, G. (1945) Season of attachment and growth of sedentary marine organisms at Oakland, California. *Ecology,* 26: 375-386.

Hewat, W.G. (1935) Ecological succession in the *Mytilus Californicus* habitat as observed in Monterey Bay. California.
Ecology, **16**: 244-249.

*Hilen, E.J. (1923) *Report on Bacteriological study of ocean slime.* Bur. Const. & Repair. Navy Dept. U.S.A.

Johnson, M.W. & Miller, R.C. (1935) The seasonal settlement of shipworms barnacles, and other wharf piling organisms at Friday harbour, Washington.
Univ. Wash. Publ. Ocean. Ogr. **2**: 1-18.

Knight-Jones, E.W., & Stephenson, F.P. (1950) Gregariousness during settlement in the barnacle *Elminius modestus* Darwin.
J. Mar. Biol. Ass. U.K., **29**: 281-297.

Kuriyan, G.K. (1950) The Fouling organisms of Pearl oyster cages.
J. Bomb nat. Hist. Soc. **49**: 21-31.

Marshall, S.M. (1933) The Production of micro-plankton in the Great Barrier Reef Region.
Sci. Rep. Great Bar. Reef. Expd. 1928-29 (2), 1-425 pp.

Mayer, A.G. (1914) Effect of temperature on tropical marine animals.
Carnegie Inst. Wash. Papers. **6**: 13-81.

McDougall, K.D. (1943) Sessile marine invertebrates at Beaufort, North Carolina.
Ecol. Monogr. **13**: 321-374.

Miller, M.A. & Cupp E.E. (1942) The development of biological acceleration tests.
Ann. Rept. San. Diego, Naval Biol. Lab. to the Bur. Ships Navy Dept. U.S.A.

Miller, M.A., Rapean, J.C., & Whedon, W.F. (1948) The role of slime film in the attachment of fouling organisms. *Biol. Bull.* 94: 143-57.

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in the Madras harbour.
Proc. Indian Acad. Sci. B. **15**: 1-42.

Pyefinch, K.A. (1948) Notes on the Biology of Cirripedes.
J. Mar. Biol Ass. U.K. **27**: 451-463.

Richard, B.R., & Clapp, W.F. (1944) A preliminary report on the fouling characteristics of ponce de Leon Tidal inlet, Daytona Beach Florida.
J. Mar. Res. **5**: 189-195.

Scheer, B.T. (1945) The development of marine Fouling communities.
Biol. Bull. **54**: 103-112.

Shelford, V.E. (1930) Geographic extent and succession in Pacific North American inter tidal (Balanus) communities.
Publ. Pudget Sound Biol. Sta. **7**: 217-224.

Smith, F.G.W., Williams, R.H. & Davis, C.C. (1950) An ecological survey of the subtropical inshore waters adjacent to Miami.
Ecology. **31**: 119-146.

Weiss, C.M. (1948) Seasonal attachment of sedentary marine organisms in Biscayne Bay, Florida.
Ecology. **29**: 153-172.

*Whedon, L.F. (1937) Investigations pertaining to the Fouling of ships bottoms.
Rept. Scripps. Ocean. Inst. La Jolla Calif. Bur. Ships Navy Dept. U.S.A.

Wood, E.F. (1950) Investigation on underwater Fouling: The role of bacteria in the early stages of fouling.
Austr. J. Mar. & Freshwater Res. **1**: 85-91.

Zobell, C.E. (1938) The sequence of events in the fouling of submerged surfaces.
Contrib. Scripps. Inst. Oceanogr., **35**: 37-102.

Zobell, C.E. (1939) The role of Bacteria in the Fouling of submerged surfaces.
Biol. Bull. **77**: 302.

* Not seen in original

J. Madras Univ., B, XXIV, No. 2, pages 213-223, 1954

Dyke Rocks of Pallavaram

BY

N. Leelananda Rao
Department of Geology and Geophysics,
University of Madras, Madras-25.

(Received for publication, May 27, 1954)

ABSTRACT

Dolerite Dykes intermediate in character between Pyroxenites and Augite-Diorite Dykes occur in Pallavaram. The average anorthite content of the plagioclase felspars of the dykes is Ab_{45} An_{55} and all the types of twin laws, normal, parallel and complex are displayed by them. Pyroxenes occur as both twinned and untwinned grains. The phenocryst pyroxenes show variation in 2V from $+50°$ to $+40°$ and the ground mass pyroxenes from $+40°$ to $+25°$. There is no break in the values of 2V from $+32°$ to $+40°$ as suggested by Hess (1941). The dolerite dykes of Pallavaram closely resemble the Cuddapah dykes in essential mineralogical and petrological characters.

Introduction

As early as (1897) Sir Thomas Holland has reported the occurrence of Pyroxenite and Augite-Diorite dykes intrusive into the charnockites of Pallavaram, and gave a detailed description of them. Since then no work was done on these dyke rocks. Recent survey of the area by the author has revealed the occurrence of dolerite dykes, intermediate in character between the above mentioned types. The dolerite dykes cut through both the basic and acid charnockites of Rifle Range and Mosque Hill of Pallavaram (Fig. 1, Plate 1) and some of them contain Xenoliths of acid charnockite. (Fig. 2, Plate 1). The trend of the dykes varies from N—S to N.N.E.—S.S.W. to N.E.—S.W. They vary in length from a few feet to one furlong, and the width ranges from a few inches to six feet. Most of these dykes are vertical but in some places there are off-shoots of these dykes along the horizontal joint planes which dip $20°$ due north. The mineralogical, petrographical and petrochemical study of these rocks forms the subject matter of this paper.

Methods of Study

Optical measurements including the determination of optic axial angle, extinction angle, orientation of parting and the nature of felspar were carried out on the Federov Universal Stage. The optic axial angle was measured directly between the emergences of two optic axes and Tröger's corrections applied for an average β value of 1·700 (the hemispheres used being of R.I. 1·648). The anorthite content and twin laws were determined according to the method of Reinhard (1931) and the complex laws checked by the methods of Nikitin (1936) and Berek (1924). As there were a number of (100) twinned grains of Augite, extinction angle was determined directly by applying Nemato and Turner's (1942) method. Refractive index β was determined on grains passed through 80 mesh and separated in bromoform and various dilutions of Clerici's solution, observing the conoscopic figures in white light and matching in sodium light. The refractive indices were read immediately on Abbe refractometer. α and γ were calculated by measuring the birefringence on Federov stage utilising felspar grains to compute thickness. The percentage of Phenocrysts in the fine-grained rocks was determined on a Leitz six-spindle integrating stage. Chemical analyses were carried out by standard chemical methods outlined by Groves (1951).

Mineralogy

The essential and abundant constituents which comprise the dolerite dykes are the plagioclase felspars, pyroxenes and opaque iron ores.

Felspars: The felspars which make up 40 to 50 percent of the bulk volume of the rock occur as elongated laths, irregular plates and minute grains. The length of the laths varies from 1 mm. to 0·01 mm. and their width ranges from 0·7 mm. to 0·003 mm. Though there are occasional untwinned laths, the majority of them show polysynthetic twinning lamellae. The results of determination of twin laws on 60 grains are shown in table I.

It is seen from the table that all the types of twin laws, normal, parallel and complex are represented in these Dolerite dykes. (010) as twin plane is more common in these dykes than (001). It is also interesting to note that only albite-ala is not represented in these rocks. Perhaps it is due to the absence of plagioclase

TABLE I

Rock Type	Number of Grains determined	Albite	Normal Law				Parallel Law			Complex Law	
			Manebach	Baveno right	Baveno left	Carlsbad	Acline = Manebach-Ala	Pericline	Ala	Albite-ala	Albite-Carlsbad
Fine-Grained Dolerite ..	22	9	1	—	—	4	1	1	—	—	6
Medium-Grained Dolerite ..	38	17	—	1	1	6	1	1	1	—	10
Total ..	60	26	1	1	1	10	2	2	1	—	16

which is intermediate in composition between oligoclase and andesine as pointed out by Coulson (1932).

The anorthite content determined on the twinned plagioclase varied from 55 to 64 percent. Some plagioclase laths show normal oscillatory zoning and the anorthite content of these range from basic andesine (AB_{52} An_{48}) at the margin to labradorite (Ab_{45} An_{55}) in the intermediate zone to acid bytownite (Ab_{28} An_{72}) at the core. The majority of the plagioclases, however, gave anorthite content of 55 percent. The optic axial angles varied from +78° to +81° and these also give an average anorthite content of the felspars as 55 percent. The refractive index β determined on several grains gave an average value of 1·561 and this confirms the average anorthite content of the plagioclase felspars as 55 percent.

The majority of the plagioclase laths show clouding due to the presence of fine magnetite dust over their surface and it is shown in Plate 1, Fig. 6. The plagioclase laths in the marginal portion of the dykes do not show this clouding.

Pyroxenes: The next abundant and important mineral is the pyroxene which is somewhat greenish in colour in thin sections. A few grains have a slight pinkish tinge possibly due to the presence of traces of titanium. The length of the pyroxene grains varies from 0·5 mm to 0·1 mm and the width ranges from 0·3 mm to 0·03 mm. Partings parallel to (100) and (010) are sometimes present in the euhedral phenocrysts and magnetite inclusions are often found along these parting planes.

The euhedral and subhedral phenocrysts of pyroxene which form 4·8 percent of the rock show variation in the optic axial angle from + 40° to +50° in the plane parallel to 010. Extinction angle Z Λ C determined directly on 20 grains which show (100) twinning gave an average value of 42°. α = 1·684—1·692; β = 1·687—1·695; γ = 1·712—1·720.

The ground mass pyroxenes show continual variation in the optic axial angle from + 40° to +25° in the plane parallel to 010. Extinction angle Z Λ C determined with reference to (110) cleavage trace gave an average value of 40°. Some grains are uniaxial. α = 1·702—1·712; β = 1·706—1·716; γ= 1·730—1·740.

A few pyroxene grains of the ground mass show zoning and invariably the core has a smaller axial angle (+ 26°) than the shell (+ 40°).

From the above mentioned optical characters it is obvious that the pyroxenes of the dolerite dykes of Pallavaram are not homogeneous but form a continuous series of mixed crystals from Diopside—rich to hypersthene—rich members. Hess (1941) groups all pyroxenes with optic axial angle below 32° under pigeonite, those above 40° under Augite and states that there is a gap between the two. Here, however, the pyroxene grains show also angles between 32° and 40° and this accords with the observation of Barth (1931). As the optic axial plane of the pigeonite is parallel to (010), it is considered as a calcic variety belonging to the clinoenstatite-diopside series as suggested by Winchell (1951).

Opaque Iron Ore: The dolerite dykes of Pallavaram contain a higher percentage of iron ore than most other plateau basalts. In the fine grained rocks the iron ore appears in the form of minute grains and fine dust and tends to be concentrated in the ground mass. In the medium grained variety it occurs as equi-dimensional granules intersertal between felspars and pyroxenes. The enrichment of magnetite in the ground mass of these rocks is of special interest for it connotes the late stage of crystallisation of iron in basaltic magmas as pointed out by Washington (1922).

Petrography

Based on the grain size, the dolerite dykes of Pallavaram can be grouped under two divisions as follows:

(i) Fine-grained variety.

(ii) Medium-grained variety.

The former constitutes the marginal facies of the dykes and the latter comprises the middle portion.

Fine Grained Variety: The average grain size of the fine-grained dolerite varies from 0·2 mm to 0·5 mm, and based on texture it can again be sub-divided into two types, vitrophyric and pilotaxitic.

The vitrophyric type is a compact dark grey rock. Under the microscope it is mainly composed of glomeroporphyritic groups of plagioclase and pyroxene embedded in a fine-grained matrix. (Fig. 3 Plate 1). The occurrence of plagioclase as idiomorphic prisms

suggests its early formation. The average anorthite content of the plagioclase is 55 percent and some of them exhibit zoning. The plagioclase laths in this rock are fresh and free from clouding. A few euhedral and subhedral phenocrysts of Pyroxene suggest that they have crystallized immediately along with the plagioclase. The phenocrysts are Augite, and the ground mass contains both augite and pigeonite. The fine grained matrix under high power is seen to be made up of an aggregate of Plagioclase, pyroxene and magnetite. In one section, brown palagonite, developing at the expense of augite and magnetite, is seen, and there is also green palagonite which is isotropic in character.

The pilotaxitic type is similar to the vitrophyric variety in essential mineralogical characters, but, there is the absence of a dense fine-grained matrix. In this rock the majority of felspar laths show clouding and their anorthite content averages to 55 percent. Some laths display zoning. Augite occurs as twinned and untwinned phenocrysts and the ground mass contains both augite and pigeonite. The ground mass is made up of a plexus of minute felspar laths with which are mingled augite and magnetite. (Fig. 4 Plate 1). Apatite occurs as minute needless in the felspar laths, and Chlorite occurs as an alteration product of augite.

Medium grained variety: This is a dark-greyish rock composed of plagioclase and pyroxene together with magnetite. The average grain size of this rock varies from 0·5 mm to 1 mm. Plagioclase which is the most abundant mineral shows clouding and the anorthite content varies from 48 to 55 per cent. The felspar laths project into augite prisms and impart to the rock a sub-ophitic texture (Plate 1, Fig. 5). Pyroxenes occurring in this rock are augite and they show alteration to hornblende and chlorite along the periphery. Magnetite occurs as inclusions in felspars and augite, and is also interstitial between them. Apatite occurs as fine needles in the felspar laths.

Petrochemistry

The marginal and middle portions of the Dolerite dykes were analysed and their weight percentages, C. I. P. W. norm and Niggli values are shown in table II. Also three more analyses of allied rocks are presented for comparative study.

TABLE II

	A	B	C	D	E
SiO_2 ..	48·21	50·15	49·20	52·11	50·61
Al_2O_3 ..	14·60	13·80	14·59	14·35	13·58
Fe_2O_3 ..	4·29	3·76	3·50	1·38	3·19
FeO ..	10·82	10·33	9·57	9·94	9·92
MnO ..	0·30	0·26	0·40	0·18	0·16
MgO ..	5·64	5·53	6·33	5·73	5·46
CaO ..	10·89	10·12	9·45	8·85	9·45
Na_2O ..	2·50	2·60	2·64	2·97	2·60
K_2O ..	0·28	0·57	0·63	1·15	0·72
TiO_2 ..	1·23	1·52	1·34	0·80	1·91
P_2O_5 ..	0·15	0·18	0·17	0·24	0·39
H_2O+ ..	0·78	0·83	2·08	2·08	1·70
H_2O- ..	0·32	0·37	0·39	0·17	0·43
Total ..	100·01	100·02	100·29	99·95	100·12
Sp. Gr. ..	3·10	3·06	3·004	—	2·96
	C. I. P. W. Norm				
Q ..	0·30	2·52	0·60	0·12	4·32
Or ..	1·67	3·34	3·34	7·23	3·89
Ab ..	20·96	22·01	22·01	25·15	22·01
An ..	27·80	24·19	26·41	22·24	23·35
Di ..	21·28	20·69	17·84	17·32	17·44
Hy ..	18·17	17·28	20·94	21·78	17·88
Il ..	2·28	2·89	2·43	1·52	3·65
Mt. ..	6·26	5·57	5·10	2·09	4·64
Ap ..	0·34	0·34	0·34	0·34	0·01
H_2O ..	1·05	1·20	2·47	2·25	2·13
	Niggli Values				
si ..	109·70	120·10	116·8	131·1	126·3
al ..	19·52	19·39	20·4	21·3	20·0
fm ..	47·46	47·84	48·6	45·6	47·3
c ..	26·68	25·86	24·1	23·8	25·3
alk ..	6·30	6·91	6·9	9·3	7·4
ti ..	2·05	2·73	2·4	1·5	3·6
p ..	0·14	0·14	0·14	0·15	0·42
k ..	0·07	0·125	0·12	0·23	0·15
mg ..	0·40	0·415	0·46	0·47	0·43

A. Marginal portion of the Dolerite Dyke of Rifle Range, Pallavaram. Analyst: N. Leelananda Rao.

B. Middle portion of the Dolerite Dyke of Riflle Range, Pallavaram. Analyst: N. Leelananda Rao.

C. Average of 8 Analyses of Cuddapah traps B to H. Proc. Ind. Acad. Sci., 1946, 23 A, 365. Analyst: N. A. Vemban.

D. Average of 5 Analyses of Newer Dolerites of Bihar and Orissa. Proc. Ind. Acad. Sci., 1946, 23 A, 365. Analysts: L. A. N. Iyer and P :C: Roy:

E. Average of 11 Analyses of Deccan traps. Bull. Geol. Soc. America., (1922) 33, 774. H. S. Washington.

From the table it is evident that the dolerite dykes of Pallavaram show a close similarity in chemical composition to Cuddapah dykes, though a distance of 200 miles intervenes between the two.

The normative composition shows occult quartz ranging in amount from 0·3 to 2·52 percent and this accounts for the absence of olivine in these dyke rocks.

The normative felspars recalculated to a total of 100 and presented in table III show that 3 to 6 per cent of orthoclase occurs in solid solution in the plagioclase. Further the percentage of anorthite content as deduced from the optical data closely matches with the normative percentage of the Plagioclase felspars. The composition of the felspars of the Dolerite dykes of Pallavaram closely resembles that of Cuddapah dykes.

TABLE III

Type Rock	Total Percentage of Felspar in the rock	Orthoclase	Albite	Anorthite
A	.. 50·43	3·31	41·57	55·12
B	.. 49·54	6·74	44·42	48·84
C	.. 51·76	6·45	42·52	51·03
D	.. 54·62	13·23	46·05	40·72
E	.. 49·25	7·90	44·69	47·41

Table IV gives a comparative idea of the metasilicates, $CaSiO_3$, $MgSiO_3$, and $FeSiO_3$ of the pyroxenes of dolerites of Pallavaram together with the allied rock types. The metasilicates of the dolerites are more or less uniform in composition with a low content of

$CaSiO_3$. The metasilicate composition of the dolerites of Pallavaram does not differ much from that of Cuddapan dykes but differs slightly from Newer dolerite in having a lower percentage of $FeSiO_3$.

TABLE IV

Rock Type	Di	Hy	$CaSiO_3$	$MgSiO_3$	$FeSiO_3$
A	.. 21·28	18·17	27·12	35·33	37·55
B	.. 20·69	17·28	27·50	36·35	36·15
C	.. 17·84	20·94	24·86	40·75	34·39
D	.. 17·32	21·78	22·25	36·57	41·18
E	.. 17·44	17·88	24·98	38·61	36·41

To know the relative order of crystallisation of felspar and Pyroxene the (f) norm of the rocks as suggested by Barth (1936) was calculated and is shown in Table V.

TABLE V

Rock Type	ab'	an'	Di'	hy'	(f) Norm.
A	.. 23·76	31·52	24·12	20·60	119·38
B	.. 22·01	24·19	20·69	17·28	122·54
C	.. 26·20	30·40	19·20	24·20	120·3
D	.. 29·30	25·60	20·40	24·70	126·90
E	.. 27·00	29·00	22·00	22·00	122·

The very close approach of the (f) norm of dolerite dykes of Pallavaram to 123 suggests that plagioclase started crystallising first and was immediately followed by Pyroxene, and that later both

pyroxene and plagioclase crystallized simultaneously. It is interesting to note that (f) norm of these dykes matches very closely with that of Cuddapah.

As it is obvious from the optical and analytical data, much of CaO must have been taken up by the early formed plagioclase laths thus impoverishing the magma in CaO. Hence, by the time, pyroxene began crystallizing the magma was depleted of its CaO content with a concomitant enrichment in MgO and FeO. This residue developed subhedral and anhedral grains of pyroxene interstitial between the felspars. Further, Hess (1941) states that if the ratio of the two oxides MgO: FeO reaches 7:3 or less, then a pigeonitic pyroxene separates out from the magma depending on the rate of cooling. This crystallization of pigeonite is further facilitated by the rapid cooling of the magma during its period of consolidation. The last mentioned factor together with the former explains the formation of pigeonite in the ground mass pyroxene of the fine-grained variety of dolerite of Pallavaram.

Niggli values show low percentages of silica, alumina and alkalies, relatively to magnesia, iron and calcium, in the analysed rock types. This points to the fact that the dolerite dykes of Pallavaram have not undergone any differentiation.

As these dykes do not show any metamorphic impress, these are considered as post-archaean and as these resemble very closely the Cuddapah dykes in mineralogical, petrographical and petrochemical characters, it is inferred that these basic dykes of Pallavaram are genetically connected to the main period of Cuddapah volcanic activity.

ACKNOWLEDGEMENT

My grateful thanks are due to Dr. P. R. J. Naidu for suggesting the problem and guiding throughout the work.

BIBLIOGRAPHY

Barth, T.F.W. (1931) Crystallization of Pyroxenes from basalts. *Amer. Miner.*, 16: No. 5, 195-208.

Barth, T.F.W. (1936) The Crystallization process of basalt. *Amer. J. Sci.*, 31: 321-51.

Berek, M. (1924) *Mikroskopische Mineral bestimmung mit Helfe der Universal drehtisch methoden.* Gebruder Borntraegar, Berlin.

Fig. 1. Field Photo of the vertical wall of dolerite dyke (DY.) intrusive into the basic Charnockite (B.Ch.) of Rifle Range.

Fig. 2. Field Photo of a xendith of acid Charnockite (Ch.) in the Dolerite Dyke (DY.) of Mosque Hill.

Fig. 3. Microphoto of fine grained dolerite showing vitrophyric texture. Glomeroporphyritic groups of Pyroxene (PY.) and Plagioclase (Pl.) are embedded in a dense fine grained matrix. × Nicols. × 35.

Fig. 4. Microphoto of fine grained dolerite showing Pilotaxitic texture. Plexus of Plagioclase (Pl.) is seen around Pyroxene (PY.) × Nicols. × 35.

Fig. 5. Microphoto of Medium grained dolerite showing subophitic texture. Laths of Plagioclase (Pl.) are seen projecting into the Pyroxene grains (PY.). × Nicols. × 35.

Fig. 6. Microphoto of Medium grained dolerite showing ophitic texture. Pyroxene grains (PY.) are enclosed by plagioclase laths (Pl.) which show clouding.

Coulson, A.L. (1932) The Albite Ala B twinning of Plagioclase felspars in certain acidic rocks from Sirohi State, Rajputana, Rec. G. S. I., 65: 173-184.

Groves, A.W. (1951) *Silicate Analysis,* Second Edition, George Allen and Unwin Ltd., 336 pp.

Hess, H.H. (1941) Pyroxenes of common mafic magmas, Pt. 1. *Amer. Miner.,* 26: 515-535.

—— (1941) Pyroxenes of common mafic magmas. Pt. 2. *Amer. Miner.,* 26: 573-594.

Holland, T.H. (1897) On some norites—and associated basic dykes and lava flows in Southern India. 30. Pt. 1, 16-42.

Nikitin, W. (1936) *Die Fedorow Methode,* Verlag von Gerbruder Borntraegar, Berlin.

Reinhard, M. (1931) *Universal Drehtischmethoden,* B. Wepf & Co., Verlag. Basel, 119 pp.

Turner, F. J. (1942) Determination of extinction angles in monoclinic Pyroxenes and amphiboles. *Amer. J. Sci.,* 240: 571-583..

Vemban, N.A. (1946) A chemical and petrological study of some dyke rocks in the Pre-Cambrian (Cuddapah Traps). *Proc. Indian Acad. Sci.,* A. 23: 347-378.

Washington, H.S. (1922) Deccan Traps and other Plateau basalts *Bull. geol. Soc. Amer.,* 33: 772.

Winchell, A.N. and Winchell, H. (1951) *Elements of optical Mineralogy,* Pt. 2. John Wiley and Sons. Inc. New York, 551 pp.

J. Madras Univ., B, XXIV, No. 2, pages 225-236, 1954

Plagioclase Felspars from Charnockites of Salem

BY

S. RAMANATHAN

Department of Geology and Geophysics, University of Madras.

(Received for publication, May 31, 1954)

ABSTRACT

The twin laws of the plagioclase felspars from the Charnockites of Salem are determined. The more abundant twin-laws are compared in a histogram. The abundance of Albite and Pericline twin-laws and the greater representation of untwinned grains are factors in favour of assigning a metamorphic character to these Charnockites. (cf. Turner and Gorai). A check on the laws is afforded by Nikitin's and Berek's constructions and also by calculating Köhler and Tertsch values, which correspond mostly to the low temperature values of the Austrian authors. Cumulative diagrams of all the poles of association planes and of the poles of twinning planes of complex twins are presented, the former shows a large dispersion.

Thirty-five rock sections cut from 13 rock types were examined. 188 Plagioclase felspar grains were determined for anorthite content and twin-laws according to the method of Reinhard (1931)—The results are presented in Table I, which also gives the rock types and the localities where they occur.

The most commonly occurring twin-laws in this series, are, Albite (71), Pericline (40), combined Albite-Pericline (36) and Albite-ala (30). Manebach and Ala count for 3 and 1 respectively. A comparative distribution of the four laws abundant in the various rock types is given in Histogram (Fig. 1).

Albite, Pericline, Combined Albite-Pericline and Albite-ala twins occur in all the three granulites. The incidence of Albite and Pericline twins is maximum in the basic, less in the Intermediate and least in the acid Charnockites. Albite-ala B law is maximum in acid Charnockites and least in the basic.

TABLE I

Normal Law		Parallel Law			Complex Law						
Albite	Manebach	Carlsbad	Pericline	Ala	Albite-Ala	Albite-Carlsbad	Combined Albite-Pericline	Untwinned	An-Content	Rock Type	Locality
5	—	—	—	—	—	—	1	—	20-25	Migamatite	Kanjamalai
—	—	—	1	—	—	—	1	7	20-30	Leptite	Kusamalai
3	1	—	12	—	—	—	—	3	20-35	Andalusite-Schist	Karuppur, Nagaramalai, and Karankaradu
4		—	6	—	10	—	6	11	25-35	Acid granulites with hypersthene (acid charnockite)	Chengaradu, Annadanapatti and foot of Shervoroys
2	—	—	1	—	—	—	1	—	25-35	Amphibolite	Karankaradu, and Salem Omalur Road
3	1	—	—	1	2	—	1	16	25-35	Hypersthene-Biotite-gneiss	Kanjamalai

—	1	—	—	—	—	—	3	4	30-35	Garnetiferous-leptynite	Karuppur
2	—	—	—	—	—	—	—	—	30-45	Mylonite	Annadanapatti
19	—	—	8	—	6	—	5	7	30-55	Garnet-diopside-Hypersthene-granulite (Intermediate charnockite)	Esangadu, Kanjamalai, Chengaradu, and Karuppur
6	—	—	—	3	4	—	3	3	35-50	Eclogite	Nagaramalai and Annadanapatti
4	—	4	—	—	—	3	—	—	40-55	Trap-rock with hypersthene	On the way to Chengaradu from Karuppur
23	—	—	9	—	4	—	15	8	45-75	Basic-granulite (Basic charnockite)	Nagaramalai, Esangadu, and Karankaradu
—	—	—	—	—	4	—	—	—	65-75	Pyroxenite	Kanjamalai
71	3	4	40	1	30	3	36 = 188	—			

Carlsbad (4) and Albite-Carlsbad (3) occur only in the trap-rocks intruding into the Charnockites series. These two laws are The histogram (Fig. 2) gives this proportion in the Charnockite

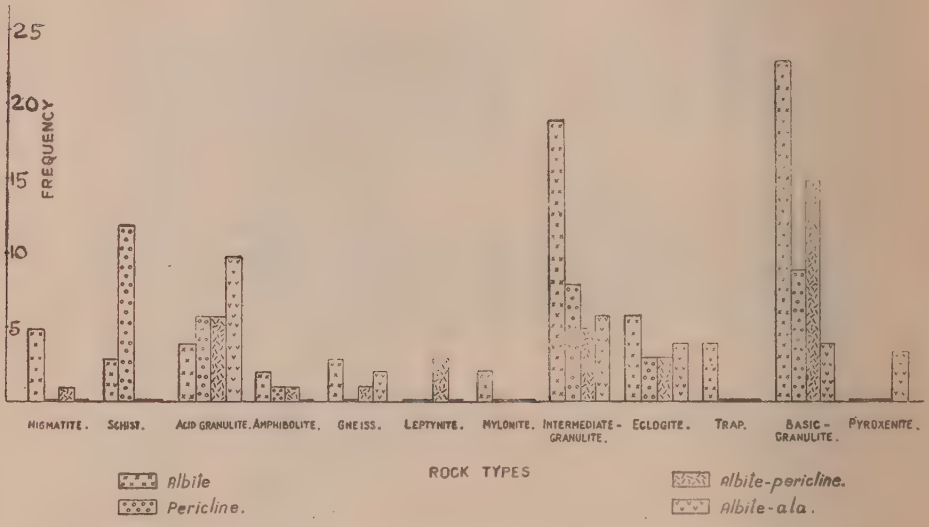


Fig. 1. Histogram representing the relative incidence of the four laws abundant in the plagioclase grains examined.

and ultrabasic members of the Charnockite series. This fact has been reported by Naidu (1950), among all the Charnockite rocks collected by him from various parts of India. Bhaskara Rao and Srirama Rao (1953), however, have recorded these laws as 'abundant' and 'good' in the basic Charnockites, and 'fairly abundant' in the intermediate Charnockites. Turner (1951), does not record any Carlsbad or Albite-Carlsbad twinning in his study of metamorphic rocks and granulites, and is of opinion that pericline twinning is as common as Albite twinning in rocks of higher metamorphic grades, except pyroxene granulites and hornfels, studied by him. In the Pyroxene granulites (Charnockites) studied here, the ratio of Albite-twinning to Pericline twinning is 2:3 (acid Charnockites), 2:1 (Intermediate Charnockites) and 5:2 (Basic Charnockites). This ratio indicates that Albite-twinning relatively to Pericline-twinning, increases towards the basic Charnockites. Combined Albite-Pericline twins are more abundant in the acid and basic Charnockites than in the intermediate.

Gorai (1951), has made a distinction between igneous and metamorphic modes of twinning, the Carlsbad and the Albite-Carlsbad laws being the most common in the former. He also comments on the proportion of untwinned to twinned Plagioclase, and infers that the proportion of untwinned is greater in metamorphic rocks. The histogram (Fig. 2) gives this proportion in the Charnockite series:

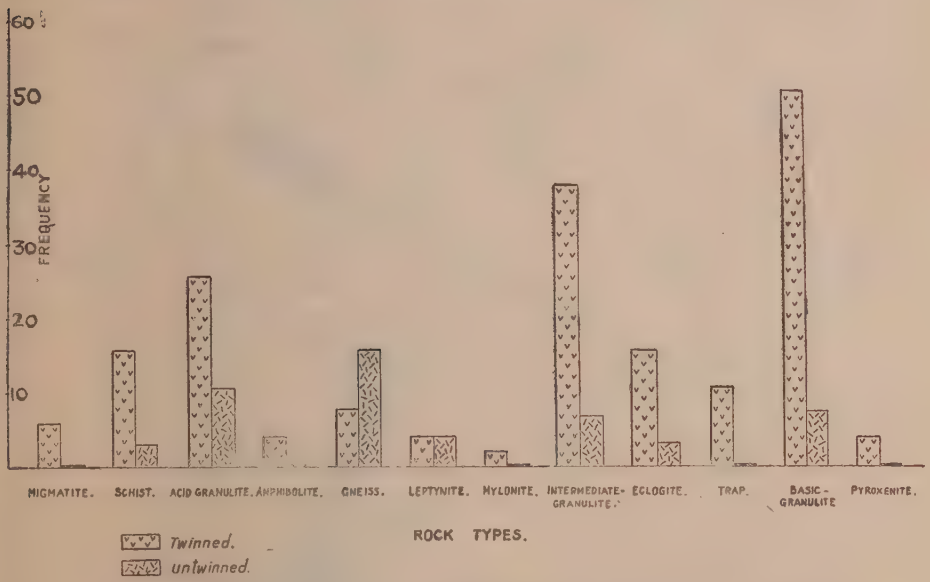


Fig. 2. Histogram representing the proportion of twinned to untwinned plagioclase grains in the rock types studied.

The proportion of untwinned diminishes towards the basic granulites and is zero in trap rocks. Considering both these factors, the plagioclase felspars of the Charnockites seem to bear a metamorphic character.

Albite-ala law deserves special notice, since it has been recorded in almost all the members of the Charnockite series, the maximum incidence being among the acid Charnockites. The conflict of interpretation between Albite-ala law and albite-law has been discussed by Coulson (1932) for the 33% An. Such conflicts were resolved by the Author by applying Nikitin's construction in all cases, and between 30-35% An, by also applying Coulson's check. The stereograms (Figs. 3 and 4) illustrate the conflicts of interpretation, one at 30% An and another at 75% An.

Fig. 3 shows the transferred poles of axes of the ellipsoid for 30% An. The gama and beta poles of both the individuals lie on the same side of the symmetry plane Ala, and the alpha poles lie very near to the circumference, and are symmetrical with reference

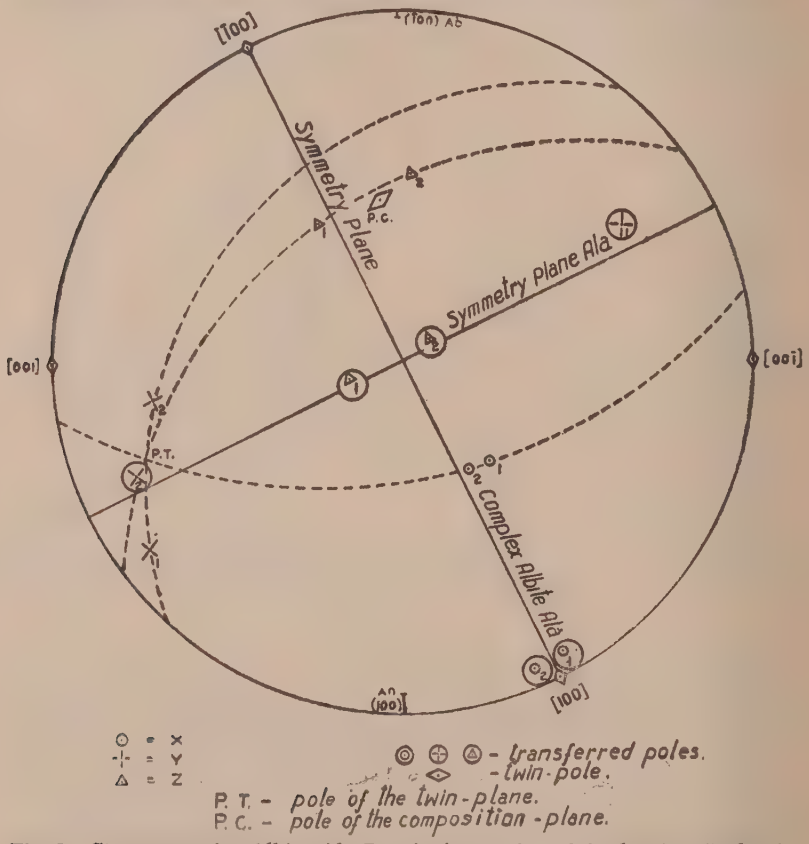


Fig. 3. Stereogram for Albite-Ala B twinning at An. 30%, showing Coulson's check and Nikitin's construction (in plate 3 of Reinhard).

to the symmetry plane of the Complex Albite-ala-B twinning. The two individuals are symmetrical about the direction (100) in the plane (010). These positions satisfy the conditions for Albite-ala B twinning, as laid down by Coulson. A further check by drawing Nikitin's construction and locating the twin pole, confirms the complex nature of the twinning, since the twin pole lies within the composition face and is 90° removed from its pole. A similar reasoning, by Nikitin's construction, confirms Albite-ala B twinning at 75% An. (Fig. 4).

A further check on the laws determined is afforded by calculating Köhler and Tertsch values for the Plagioclase grains of Charnockites and comparing them to the values given by these Austrian authors for the various laws and anorthite percentages.

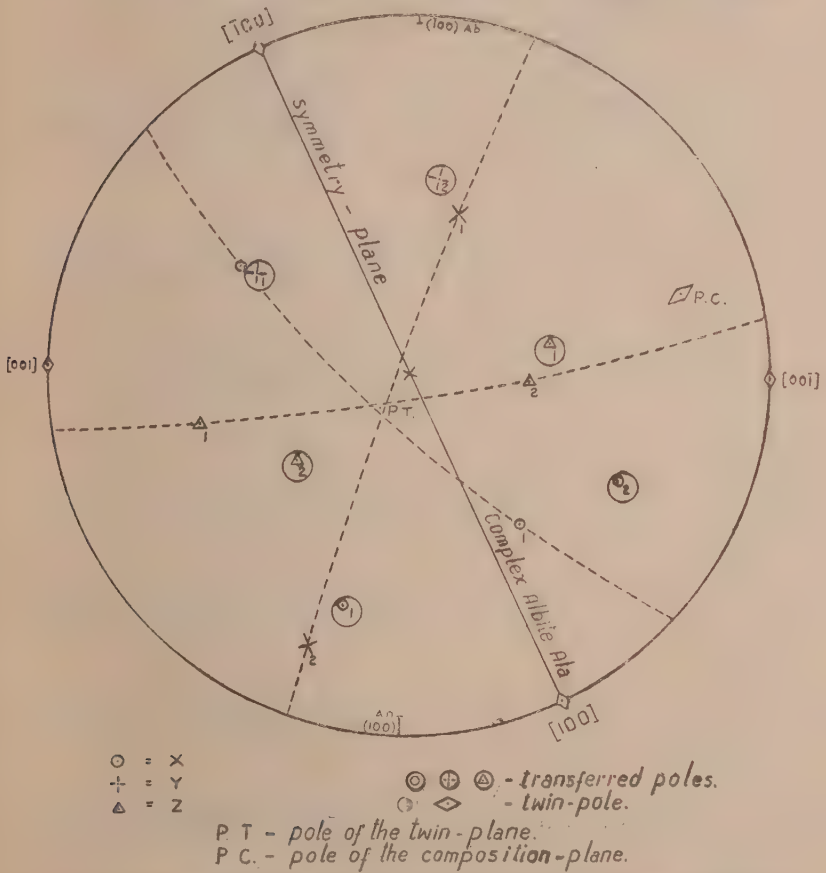


Fig. 4. Stereogram showing Albite-Ala-B twinning at An. 75% and Nikitin's construction (in plate 3 of Reinhard).

The köhler values are (1) the angles measured between the poles of corresponding ellipsoidal axes of the two individuals of a twin (aa', $\gamma\gamma'$; $aa\pi$ $\gamma\gamma\pi$; a_1a_2 $\gamma_1\gamma_2$; a_1a_2' $\gamma_1\gamma'$) and (2) the angles between the optic axial planes of the two individuals (1, 1'; 1, 1π; 1, 2; 1, 2';). These values as well as the values recorded by the author are given in Table II.

TABLE II

Law	Anorthite Content	Ramanathan		Tertsch		Köhler		Angle Between Optic Axial Planes	
		aa'	*yy'*	*aa'*	*yy'*	*aa'*	*yy'*	As measured from stereogram 1,1'	As calculated from the graph 1,1'
Albite	27	175	20	178	20	—	20	21	21
„	28	178	22	178	23	—	22	24	22
„	29	176	24	179	25	—	24	24	24
„	30	176	24	179	27	180	26	25	27
„	35	177	36	178	37	179	36	35	37
„	40	171	44	174	43	172	44	42	41
„	48	163	52	162	50	161	52	48	47
„	50	161	56	159	54	159	56	51	48
„	55	153	57	153	59	152	60	51	51
„	70	132	77	133	81	133	77	56	57
„	72	129	80	131	79	131	79	57	57
„	73	132	80	130	80	130	80	62	57
„	75	127	80	128	82	128	82	56	56
		aaπ	*yyπ*	*aaπ*	*yyπ*	*aaπ*	*yyπ*	11π	11π
Pericline	24	178	19	179	19	—	19	19	18
„	25	178	21	179	19	—	19	22	22

„	27	179	27	180	27	—	27	26	26
„	28	178	28	—	26	—	28	28	28
„	30	175	33	180	34	—	34	32	34
„	32	178	38	179	38	—	38	36	39
„	34	171	41	178	42	179	42	42	42
„	35	178	46	178	44	179	41	45	44
„	38	176	48	176	49	175	49	48	47
„	45	161	56	165	57	165	57	52	52
„	50	157	62	157	62	157	62	56	55
„	52	153	70	154 ⊙u 154	64 74 ⊙u	154	64 72 ⊙u	63	56 — ⊙u
„	55	153	66	150	66	150	67	60	57
„	65	127	87	135 ⊙u 127	80 87 ⊙u	136 No high temp. value	79	63	61
„	70	130	82	129	85	129	84	59	62
		a_1a_2	y_1y_2	a_1a_2	y_1y_2	a_1a_2	y_1y_2	1,2	1,2
Carlsbad	42	79	46	76	42	78	40	80	90
„	45	86	41	83	43	83	43	81	81
		a_1a_2'	y_1y_2'	a_1a_2'	y_1y_2'	a_1a_2'	y_1y_2'	1,2'	1,2'
Albito-Carlsbad	45	97	23	95	21	95	21	79	80

a = alpha α
y = gama γ

It is seen that there is a close agreement between these values and they are mostly the low temperature values of Köhler and Tertsch. An exception was noticed in the case of the felspars of only one rock (a basic granulite),—the values of which correspond to the high temperature value of the Austrian authors.

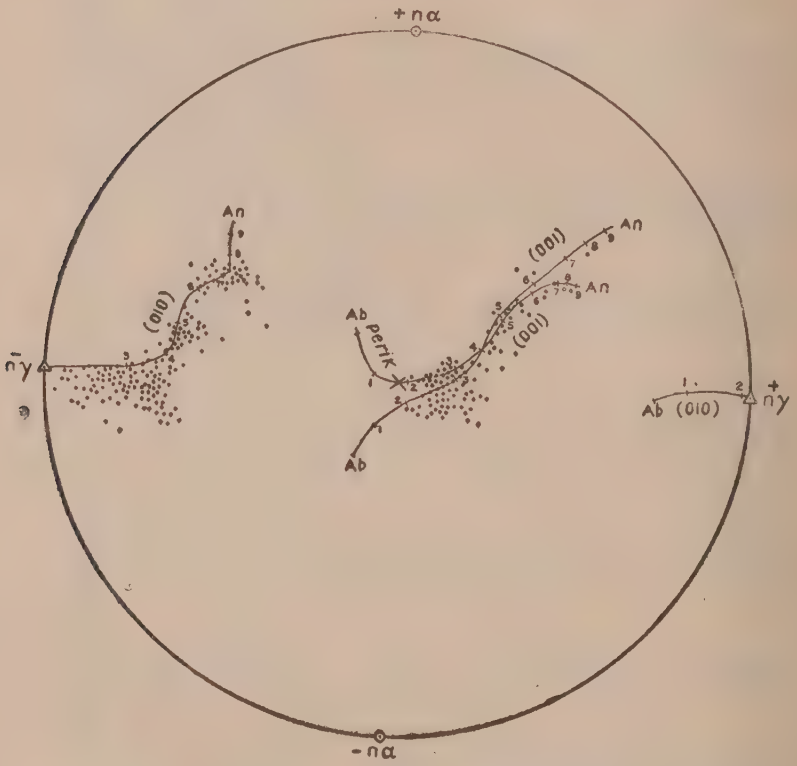


Fig. 5. Cumulative diagram of poles of composition faces for the An-content of the plagioclase felspars, in plate 2 of Reinhard. The figure shows a large dispersion of the poles.

A cumulative diagram of all the poles of association planes (composition face) is presented in Fig. 5, and of the poles of twinning planes of complex twins (located by Nikitin's and Berek's methods), in Fig. 6.

Fig. 5 shows a large dispersion of the poles, indicating according to Tertsch, the existence of high temperature optics as different

from low temperature optics. Tertsch (1941) remarks, "Zusam menfassend muB man festellen, daB die Abwei-chungen der optischen orientierung des synthetischen Anorthites Von der bisher für den reinen anorthit angegebenen zwar nicht auffalend groB, Aber dafür sehr beZeichnend sind und damit das vorhandensein einer Hochtemperatur-optik eindeutig bestätigen." Fig. 6, however, does not show such a large dispersion. Campbell-Smith (1928) has remarked that the plotting of twin poles is of a greater order of accuracy than plotting of poles of composition faces.

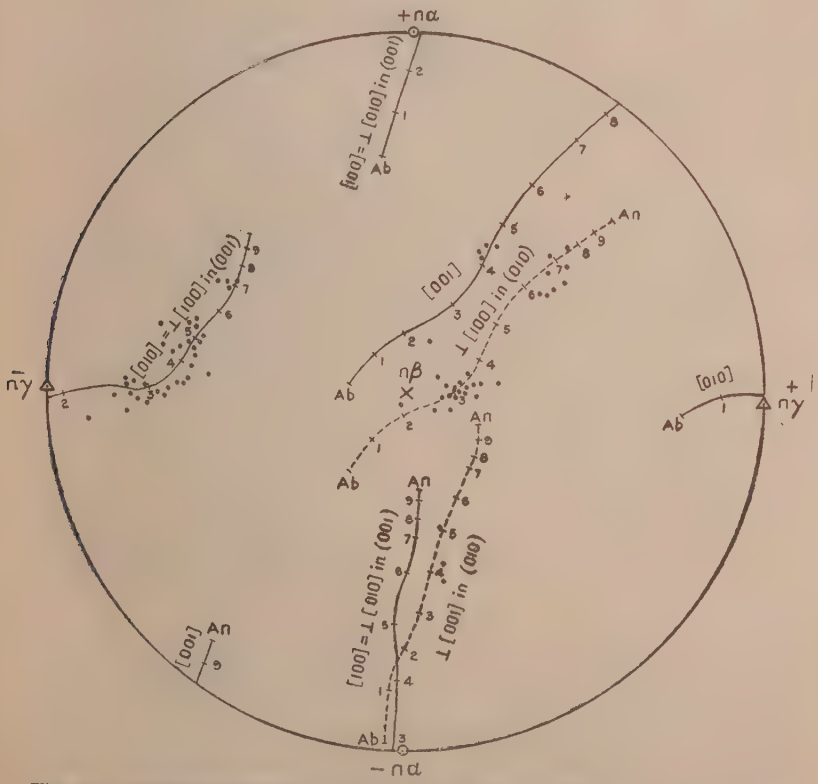


Fig. 6. Cumulative diagram of the poles of twinning planes of complex twins, in plate 5 of Reinhard. The figure does not show such a large dispersion as in Fig. 5.

ACKNOWLEDGEMENT

The author is highly grateful to Dr. P. R. J. Naidu, for his very kind help in the work.

REFERENCES

Bhaskara Rao, A. & Srirama Rao, M. (1953) Some observations on the plagioclase twinning in charnockitic rocks. *Proc. nat. Inst. Sci. India,* **19**: 501-506.

Coulson, A. L. (1932) The Albite-Ala-B twinning of plagioclase felspars in certain acidic rocks from Sirohi State, Rajputana. *Rec. geol. Surv. India,* **65**: 173-184.

Gorai, M. (1951) Petrological studies on plagioclase twins. *Amer. Min.,* **36**: 884-902.

Köhler, A. (1941) Die Abhängigkeit der Plagioclas-Optik Vom Vorangegangenen Wärmerverhalten, *Miner. Petrogr. Mitt.* **53**: 24-50.

Naidu, P. R. J. (1950) The twin laws of the plagioclase felspars of charnockites, *Curr. Sci.,* **19**: 51-52.

Reinhard, M. (1931) *Universal .Drehtischmethoden,* Verlag Von. B Wepf & Cie, Basel. 119 pp.

Smith, C. (1928) The optical orientation of labradorite from county Down, *Miner. Magazine,* **21**: 543-551.

Tertsch, H. (1941) Die optische Orientierung der Hochtemperatur-Anorthites. *Miner. Petrogr. Mitt.,* **53**: 50-67.

Turner, F. J. (1951) Observations on twinning of plagioclase in metamorphic rocks, *Amer. Min.,* **36**: 581-590.

J. Madras Univ., B, XXIV, No. 2, pages 237-243, 1954

Commentaria Herbarii

"Presidency College", Madras-5

3. Vascularization of the three-stamened—three-carpelled flowers of *Nyctanthes arbor-tristis* L.

BY

S. Rajan

Department of Botany, Presidency College, Madras-5

(Received for publication, May 1, 1954)

ABSTRACT

The vascular anatomy of the three-stamened—three-carpelled flowers of *Nyctanthes arbor-tristis* is studied. In all essentials the general ground plan resembles that of the two-stamened—two-carpelled flowers, the minute differences being only the concomitant modifications of the increased number of stamens and carpels.

The number of traces that enter a single member of the calyx, corolla and gynoecial whorls is far greater as compared with other investigated representatives of the family. The behaviour of the ovule trace in *Nyctanthes* (whether in the normal flowers or in the three-stamened—three-carpelled flowers) also appears to be slightly different from the norm of the family. The presence of concentric vascular bundles in *Nyctanthes* appears to be a feature common to *Olea*, although their proportion is subject to fluctuation.

Introduction

The oriental genus *Nyctanthes* was instituted by Linnaeus (1737) 217 years ago. The allocation of this genus to Oleaceae was accomplished by Jussieu some hundred years ago, from which time the genus has remained undisturbed. Very recently, this oleaceous alliance of *Nyctanthes* has been seriously questioned by Airy Shaw (1952), and he transfers the genus as a member of the Verbenaceae. He states that "the plant bears very little resemblance to a *Jasminum*, or, for that matter, to any member of the Oleaceae." Such a change of the taxonomic position appears to have been surcharged by Bor (1953) in his recently published "Manual of Indian Forest Botany."

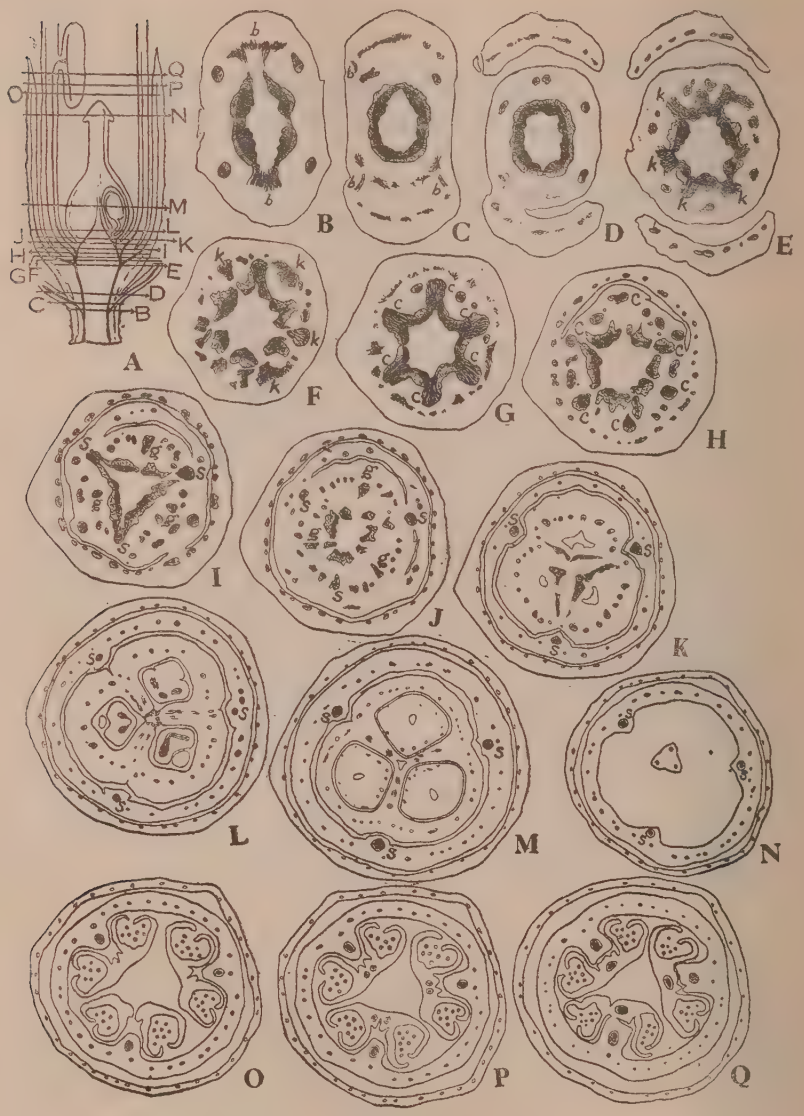


Fig. 1. *Nyctanthes arbor-tristis*

A—Semi-diagrammatic median longitudinal section of the flower; B-Q—Transverse sections of a single flower at the approximate levels indicated by corresponding lettering in A; *b*—vascular supply to bract; *c*—vascular supply to corolla; *g*—vascular supply to gynoecium; *k*—vascular supply to calyx; *s*—vascular supply to stamens. B — M × 15; N — Q × 9.

Fig. 2-4. *Nyctanthes arbor-tristis.*

Fig. 2 Corolla tube of three-stamened flower split longitudinally and opened out $\times 1{\cdot}5$; Fig. 3. Similar flower as seen from above $\times 1{\cdot}5$; Fig. 4. Transversely cut surface of a tricarpellary fruit $\times 1{\cdot}5$.

This change is certanly of a major category, and a daring one too, especially considering the grounds given by Airy Shaw which are of a rather slender nature. Therefore, it becomes necessary to gather and evaluate data from other branches of botanical discipline, such as embryology, wood anatomy, pollen morphology, etc. While collecting materials to initiate studies on these aspects (which are in progress in this laboratory) three-stamened—three carpelled flowers were also met with. This condition occurs, although sporadically, in almost every plant in the neighbourhood of Madras. Thus, each plant bears, along with the norm condition (two-stamened—two-carpelled), a varying proportion of flowers with three stamens and three carpels. It must be emphasized that the occurrence of the latter kind of flowers appears to be more than a teratological phenomenon, not only because an equal number of stamens and carpels go hand in hand with each other, but also because such flowers develop into normal tricarpellary fruits producing viable seeds (Fig. 4). It is suspected that detailed anatomical investigations of these flowers may throw more light, not only on the behaviour of vascular bundles as compared with those of the norm flowers, but also contribute towards a better understanding of the natural affinities of the genus.

The floral anatomy of the two-stamened—bicarpellary flowers has been studied by Fotidar (1942). During the present investigation the vascular anatomy of both types of flowers was studied. In all essentials the account given by Fotidar is confirmed. Deviations from his observations will be indicated in the appropriate places in the text.

Observations

The flowers with trimerous androecium and gynoecium are very similar to the bimerous ones in external appearance. The three epipetalous stamens in the former case become free towards the mouth of the corolla tube (Fig. 3). The free part of the filament is extremely short and the fused part can be distinctly seen as a longitudinal ridge extending towards the base (Fig. 2). The disposition of the gynoecium is alternating in relation to the androecial members. The ovary is trilocular with one erect anatropous ovule in each locule. The stylar region is short which ends distally in a triangular pyramid shaped stigma. The fruit is triquetrous, the sides of which are somewhat depressed. In conformity with this, the seeds also show a pronounced longitudinal concavity

(Fig. 4). When the fruit is ripe it splits apart into three one-seeded compartments.

A transverse section of the peduncle shows a similar disposition of the vascular tissues as that of the vegetative axis, i.e., a central stele plus four inversely oriented bundles in the cortex corresponding to the corners of the quadrangular stem. The vascular supply to the bracts originates in the form of an arc from the stelar vascular ring (Fig. 1, B). Soon after separation from the ring the arc becomes split up into a number of strands (Fig. 1, C-E). This set of strands is joined by branches of the cortical bundles on the corresponding sides (Fig. 1, C). This behaviour of the cortical bundles resembles their course in connection with the vascularization of the leaf (Majumdar, 1941). This situation suggests a morphological alliance of the bract to a vegetative leaf. At higher levels in the bracts the bundles exhibit further branching.

The axis between the bract and the calyx represents the pedicel. In this region each of the cortical bundles again bifurcates and the branches that are situated near the axis of the bract move towards each other, so that they occupy a position opposite the midrib of the bract (Fig. 1, D). At higher levels they may sometimes completely fuse with each other so that six cortical bundles occupy more or less equidistant places in the cortex (Fig. 1, D,E.). Higher up, the central stele gives out a variable number of traces some of which become further split up. These vascularize the calyx in part. The six cortical bundles also simultaneously branch further and intermix with the branches of the calyx traces, thus completing the vasculature of the calyx whorl (Fig. 1, E-P). A similar behaviour is seen to occur in the normal flowers also.

After the departure of the calyx traces, six large traces are given off from the central stele from radii approximately alternating with those of the calyx whorl, and these are concerned in the vascularization of the corolla (Fig. 1, G). Above this level the dorsal carpellary traces take their origin from the axial stele in three sectors (Fig. 1, I). At about the same time three staminal traces tend to depart from the axial stele from radii alternating with those of the dorsal traces of the carpels (Fig. 1, I). The stele now presents a triangular outline. In addition to the dorsal bundle, each carpel derives a considerable number of rather feebly developed strands. Some of these are seen to arise from the system of bundles that supplies the calyx whorl. With the differentiation of

the staminal traces and the dorsal carpellary traces, the axial stele loses its definiteness and appears as composed of poorly differentiated strands scattered in the centre of the thalamus (Fig. 1, J). These bundles continue upwards and supply the wall tissue of the carpels. A few of the branches tend to be disposed towards the ventral side of the carpel and these function as ventral bundles. The supply to the ovules arises from these bundles (Fig. 1, K, L). To begin with, the ovule is supplied with a single trace, which becomes further split up into a number of branches and ramify in the integument (Fig. 1, L, M). The dorsal carpellary traces continue their course upwards as far as the base of the stigma (Fig. 1, N); the supernumerary bundles in the carpellary wall run only up to the top level of the ovary proper.

The staminal trace becomes split up into two as soon as it enters the anther and the branches spread vertically in opposite directions. The branch that is directed towards the base again bifurcates (Fig. 1, A; also O-Q), whereas the one directed towards the apex does not appear to suffer any change.

It is a general phenomenon for the vascular bundles that supply the bracts, calyx, corolla and gynoecium to become split up into a large number of smaller traces and spread out at higher levels of the concerned structures.

Attention may also be drawn to the occurrence of inversely oriented bundles, concentric bundles and intergrading conditions at various levels of the flower. The inverse orientation of the cortical bundles appears to be a fairly stabilized feature wherever the identity of their derivatives remains distinct. Th concentric nature, however, appears to establish itself in bundles which do not belong to the cortical system. Furthermore, it must be pointed out that several smaller bundles, irrespective of their origin, appear concentric at specific levels, whereas they remain normally oriented elsewhere. The concentricity is maintained rather consistenly only in the staminal traces, although at the point of their origin, they show a normal orientation.

Conclusions

The general pattern of vascularization of the floral parts of the three-stamened—three-carpelled flower follows a similar ground plan as has been described for the two-stamened—two-carpelled flower. The vascular supply to the bracts, calyx and corolla is remarkably similar in the two kinds of flowers. The numerical

difference in the essential organs of the flower is reflected in the corresponding number of vascular traces that are concerned with the supply to these structures. As a concomitance the stele also changes its shape as seen in transverse sections (compare Fotidar's figures 12-14 with Fig. 1 E-K in the present text) and undergoes mutual readjustments.

The literature that is available on the vascular anatomy of the oleaceous flowers is very meagre. Only the flowers of *Osmanthus* (Joshi, 1942), *Olea* (Joshi & Fotidar, 1941), *Jasminum* and *Syringa* (Joshi & Fotidar, 1940) have been investigated from anatomical stand-point. Although the above contributions form an unusually small representation of the family, in certain respects atleast, the results may be utilized for comparison with the situation in *Nyctanthes*. In the former two genera the number of vascular strands supplying the floral parts is considerably less than in *Nyctanthes*. It is reported that in *Olea fragrans* (Joshi & Fotidar, 1941) the calyx in some flowers is totally without any vascular supply, while in others there are only poorly developed traces which die out in the thalamus itself. In the male flowers of *Osmanthus suavis*, however, the calyx is supplied by four midrib and four commisural bundles. In *Nyctanthes* this whorl receives a quite well-developed system of vasculature in which the axial stele as well as the cortical bundles are involved. In *Olea* the carpel is supplied by three main bundles, and the rudimentary carpels in the male flowers of *Osmanthus* also appear to receive three main traces which, however, are feebly developed. In *Nyctanthes* not only the carpels receive well-developed vascular bundles, but also an unusually large number as compared with the other investigated genera. The essential point of similarity between *Olea* and *Nyctanthes* concerns the occurrence of concentric bundles. It is also interesting to note that medullary bundles are present in some species of *Jasminum*, and such bundles show a variable orientation—collateral with normal or inverse orientation, bicollateral and concentric. To what extent these similarities and differences between *Nyctanthes* on the one hand and the other members of the Oleaceae on the other are significant in considerations of the systematic position of *Nyctanthes* will form the subject of future publications in the series.

ACKNOWLEDGMENT

The author wishes to express his heartfelt thanks to Dr. B. G. L. Swamy, Chief Professor of Botany, for his kind help and encouragement during the investigation.

LITERATURE CITED

Airy Shaw, H. K., (1952) Note on the taxonomic position of *Nyctanthes* L. and *Dimetra* Kerr. *Bull. Misc. Inform.* Kew 1952: 271.

Bor, N. L., (1953) *Manual of Indian Forest Botany*, pp. 441, London, Oxford University Press.

Fotidar, A. N., (1942) Floral anatomy of *Nyctanthes arbor-tristis* L. *J. Indian bot. Soc.*, 21: 159-166.

Joshi, A. C., (1942) Structure of the gynoecium in *Osmanthus suavis* King, *J. Indian bot. Soc.*, 21: 331-337.

Joshi, A. C., & Fotidar, A. N. (1940) Floral anatomy of the Oleaceae, *Nature*, 145: 354-356.

—— (1941) Floral anatomy of *Olea fragrans* Thumb. *Proc. Nat. Inst. Sci. India*, 7: 369-375.

Linnaeus, C., (1737) Genera Plantarum, Ed. I. p. 333.

Majumdar, G. P., (1941) Anomalous structure of the stem of *Nyctanthes arbor-tristis* L. *J. Indian bot. Soc.*, 20: 119-122.

J. Madras Univ., B, XXIV, No. 2, pages 245-250, 1954

Bluish-Green Hornblende from an amphibolite of Jalarpet

BY

V. M. RAGHAVAN,

Department of Geology and Geophysics,
University of Madras, Madras-25.

(Received for publication, May 28, 1954)

ABSTRACT

The hornblende was separated from an amphibolite in bromoform and various dilutions of Clerici's solution. Its chemical composition and optical characters were determined. Therefrom it is concluded that it corresponds to amphiboles occurring in gabbros.

Hornblende from an amphibolite, occurring in the granite complex of Jalarpet has been chemically analysed and its optical characters determined. The amphibolite is dark-green in colour, the schistose bands of hornblende, alternating with streaks and lenticles of felspathic bands. Occasional grains of quartz are also seen under the microscope in the felsic bands. The felspars have an anorthite content of 20-25%. Rarely there are grains having an anorthite content of 40-45%.

The hornblende was separated repeatedly in bromoform, and then in Clerici's solution, diluted with water. The chemical composition is as follows. The C. I. P. W. norms and Niggli Basis are also given in Table I.

The C. I. P. W. norms indicate that this mineral can be derived from a rock composed of plagioclase—Ab_{56} An_{44} and diopside (a gabbro).

The Q. L. M. values of this mineral when plotted on Niggli's diagram (1945, p. 88—Fig. 54) for hornblendes of eruptive rocks give a point just outside the field indicating that the hornblende does not belong to the normal eruptive types.

TABLE I

Constituents	Percentages	Mol. Props.	Basis 24 (O, OH, F.)		C.I.P.W. Norm		Niggli values Mols		%	
SiO_2	45·05	0·751	6·841		Orthoclase:	1·11%	Kp:	12	0·68	
TiO_2	1·45	0·019	0·173	8·00	Albite:	13·62%	Ne:	156	8·85	L = 15·56.
Al_2O_3	6·45	0·064	1·663		Anorthite:	10·01%	Cal:	108	6·13	
					Diopside:	19·25%				
Fe_2O_3	4·25	0·027	0·492			7·39%	Cs:	249	14·14	
FeO	15·70	0·218	1·986	5·79		11·00%	Fs:	81	4·59	
MnO	0·10	0·001	0·091		Hypersthene:	0·66%	Fa:	327	18·56	M = 66·80.
MgO	13·35	0·334	3·042			1·20%	Fo:	501	28·43	
CaO	11·33	0·202	1·841		Olivine:	14·50%	Ru:	19	1·08	
Na_2O	1·60	0·026	0·474	2·32		11·42%				
K_2O	0·02	—	—							
$H_2O + 110°$	0·72	0·040	0·729	= 0·73	Magnetite:	6·26%	Q:	309	17·54.	= Q = 17·54.
$H_2O - 110°$	0·48	—	—		Ilmenite:	2·89%				
	100·50					99·31		1762		100·00
					Water	1·20				
					Total	100·51				

For comparison with Winchell's (1924) and Hallimond's (1943) studies of calciferous amphiboles, the chemical analysis is

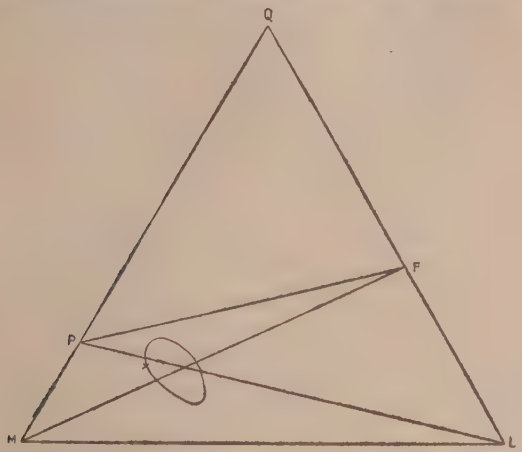


Fig. 1 Q-L-M diagram after Niggli (1945, p. 88, Fig. 54)
× = Point of analysed hornblende.

cast into Winchell's metasilicate molecules; and also, the different number of atoms, and "atoms in vacant space" are calculated. These are presented in Table II.

TABLE II

Winchell's Metasilicate Molecules

Molecules		Analysed Mineral	Nearest of Winchell's for Comparison
$CaMgSi_2O_6$	..	26·37	29·38*
$Ca(Fe,Mn)Si_2O_6$	..	19·84	19·86
$MgSiO_3$	..	21·20	15·13
$(Fe,Mn,)SiO_3$	..	18·39	10·78
$(Na,K)AlO(F,OH)_2$	..	5·60	11·21
Al AlO_3	..	3·67	7·67
Fe FeO_3	..	4·32	7·25
Ti TiO_3	..	1·45	—
	Total ..	100·80	101·28
H_2O Deficit	..	—	1·08
H_2O Excess	..	0·40	—
SiO_2 Deficit	..	0·40	0·16
	Total ..	100·80	100·04

* Hornblende, Mte. Somma, Italy, S. L. Penfield and F. C. Stanley, A.J.S. Vol. 23; p. 31; 1907.

Analysis of Amphibole Calculated to Atomic Ratios for (O, OH, F) = 2400 (After Hallimond)

	Si	Al	Ti	Fe″	Fe‴	Mn	Mg	Ca	Na	K	H	V
Analysed Mineral ..	751	128	19	54	218	1	334	202	52	4	78	283
Nearest in Hallimond's for comparison ..	742	124	4	23	68	3	349	210	12	11	92	273
Do. ..	758	54	—	39	101	1	333	222	32	2	121	—

When the silica value and the values of "atoms in the vacant space" are plotted in Hallimond's diagram (1943, p. 75), the point

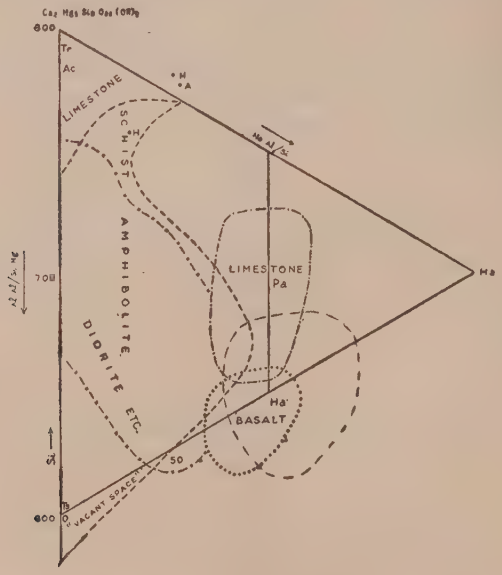


Fig. 2. Approximate limits of composition of amphiboles derived from various rocks (after Hallimond 1943, p. 75.

Ha′ = $Ca\,Na_2\,Mg_5\,Al_2\,Si_6\,O_{22}\,(OH)_2$
Ts = $Ca\,Mg_3\,Al_4\,Si_6\,O_{22}\,(OH)_2$
A = Point of analysed hornblende.
H = Nearest of Hallimond's for comparison.

falls beyond the limestone and schist field. The paragenesis corresponds to amphiboles occurring in gabbros.

The optical characters of the mineral are, $\alpha=1\cdot637$, $\beta=1\cdot656$, $\gamma=1\cdot662$, $-2V=55°$, Dispersion $\varrho > v$, A is less dispersed than B; $Z \Lambda C = 20°$, X = Yellow, Y = Dirty green, Z = Bluish green; Absorption $X < Z < Y$. β is the average of six determinations, by Immersion method, on grains showing optic axis interference figures. α and γ are computed from Birefringencies, and are the average of thirteen determinations. Optic axial angle is the average of eight determinations, on sections showing the emergence of both the optic axes. $Z\Lambda C$ is the average of four determinations from stereographic projection. Dispersion was determined on a monochromator. The structural formula of the mineral is:

$(OH)_{.73}$ (Na, Ca, K)$_{2\cdot32}$ (Mn, Fe″, Fe‴, Mg, Al)$_{5\cdot79}$ (Si, Al, Ti)$_8$ $O_{23\cdot27}$.

I am thankful to Dr. P. R. Jagapathy Naidu for suggesting this topic to me and for his constant guidance.

REFERENCES

Burri, C. & Niggli, P. (1945) *Die Jungen Eruptivgesteine des mediterranen Orogens,* Kommissionsverlag von Guggenbuhl & Huber, Schweizer Spiegel Verlag, p. 88.

Hallimond, A.F. (1943) On the Graphical Representation of the Calciferous Amphiboles, *Amer. Min.* 28: 65-89.

Winchell, A. N. (1924) Studies in the Amphibole Group, *Amer. J. Sci.,* 7: Ser. 5; 278-310.

J. Madras Univ., B, XXIV, No. 2, pages 251-272, 1954

The Distribution of t_1 and Its Applications*

BY

N. MARAKATHAVALLI

(Received for publication, March 24, 1954)

ABSTRACT

In this paper, the distribution of t_1, the ratio of a normal deviate N(0,1) to a non-central χ with n degrees of freedom and parameter λ, multiplied by $\sqrt{n}$, is obtained, and its probability integral and percentage points are derived using an approximation to the distribution of t_1 by that of a weighted t. A test of significance of the difference of the means of two 'mixed' samples is developed, using this distribution of t_1. The validity of the test when the two variances are unequal, is examined.

INTRODUCTION

If ξ is a normal variate N(o, σ) and $\chi^2 = \sum_{i=1}^{n} \frac{x_i^2}{\sigma^2}$ where the x_i's are nomal variates with mean zero and standard deviation σ, and independent of ξ, then $\frac{\xi\sqrt{n}}{\sqrt{\Sigma x_i^2}}$ is distributed as a t with n degrees of freedom. Suppose, however, that the x_i's are normal variates with a common standard deviation σ, but with different means $E(x_i) = a_i$, $i = 1, 2, \ldots n$, then $\sum_{i=1}^{n} \frac{x_i^2}{\sigma^2}$ is distributed as a χ'^2 or a non-central χ^2 with n degrees of freedom and parameter $\lambda = \sum_{i=1}^{n} \frac{a_i^2}{\sigma^2}$. If ξ is still an independent normal variate N(0, σ), the ratio $\frac{\xi\sqrt{n}}{\sqrt{\Sigma x_i^2}}$ is no longer distributed as a t. We shall denote this ratio by t_1. The distribution of t_1 may be considered as a

* This paper forms part of my Thesis "Studies in Significance Tests" approved by the University of Madras for the M.Sc. Degree in statistics.

non-central distribution, a different one from that of $t' = \frac{\xi + \delta}{\chi}$ where the non-centrality occurs in the numerator.

1·1. *The distribution of* $t_1 = \frac{\xi\sqrt{n}}{\chi'}$

The ratio $\frac{\xi\sqrt{n}}{\sqrt{\Sigma x_i^2}}$ defined above as t_1 is in the form of a ratio of a normal variate ξ with mean zero and standard deviation unity, to a non-central χ with n degrees of freedom and parameter λ, multiplied by $\sqrt{n}$. Thus

$$t_1 = \frac{\xi\sqrt{n}}{\chi'}. \qquad \ldots \quad (1)$$

The distribution of ξ is given by

$$p(\xi)\,d\xi = \frac{1}{\sqrt{2\pi}} e^{-\xi^2/2}\,d\xi$$

and that of χ'^2 by

$$p(\chi'^2)\,d\chi'^2 = \sum_{j=0}^{\infty} e^{-\lambda/2} \frac{(\lambda/2)^j}{j!} \frac{e^{-\chi'^2/2}(\chi'^2)^{(n/2)+j-1} d\chi'^2}{2^{(n/2)+j}\,\Gamma((n/2)+j)}.$$

Writing $v = \frac{\xi}{\chi'}$,

$$p(v, \chi') = \frac{1}{\sqrt{2\pi}} e^{-\xi^2/2} \sum_{j=0}^{\infty} \frac{e^{-\lambda^2/2}(\lambda/2)^j}{j!} \frac{e^{-\chi'^2/2}(\chi'^2)^{(n/2)+j-1}}{2^{(n/2)+j}\,\Gamma((n/2)+j)} 2\chi' \times \chi'.$$

Integrating out χ', we get

$$p(v) = \int_0^{\infty} \frac{e^{-v^2\chi'^2/2}}{\sqrt{2\pi}} \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \frac{e^{-\chi'^2}(\chi'^2)^{(n/2)+j-1/2}}{2^{(n/2)+j}\,\Gamma((n/2)+j)} d\chi'^2$$

$$= \frac{1}{\sqrt{2\pi}} \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!\,2^{(n/2)+j}\Gamma((n/2)+j)} \int_0^{\infty} e^{-\chi'^2(1+v^2)/2}(\chi'^2)^{(n/2)+j-\frac{1}{2}} d\chi'^2$$

$$= \frac{1}{\sqrt{2\pi}} \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!\,2^{(n/2)+j}\Gamma((n/2)+j)} \cdot \frac{\Gamma((n+1)/2+j)\,2^{(n+1)/2+j}}{(1+v^2)^{(n+1)/2+j}}$$

$$= \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!\,\mathrm{B}(\tfrac{1}{2},\ (n/2)+j)\,(1+v^2)^{(n+1)/2+j}}$$

Since $t_1 = v\sqrt{n}$, we obtain

$$\mathrm{P}(t_1)\,dt_1 = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!\,\mathrm{B}(\tfrac{1}{2},\ (n/2)+j)\,(1+(t_1^2)/n)^{(n+1)/2+j}} \cdot \frac{dt_1}{\sqrt{n}} \qquad (2)$$

Thus the probability density function of t_1 is the sum of a series of weighted probability density functions of $t/\sqrt{n}$, the number of degrees of freedom being successively $n, n+2, n+4, \ldots$, while the weights are terms of a Poisson series. We shall call n the degrees of freedom and the λ the non-central parameter of the t_1 distribution in (2).

1·2 *Properties of the t_1-distribution.*

Since t has a symmetric distribution, it is seen from (2) that t_1 is also symmetrically distributed. Therefore its moments of odd order are zero, i.e., $\mu_{2r+1}(t_1) = 0$.

The $2r^{\text{th}}$ moment of $(t/\sqrt{n})$ with m degrees of freedom is $\dfrac{\mathrm{B}((m/2)-r,\ r+\frac{1}{2})}{\mathrm{B}(m/2,\ \frac{1}{2})}$. Since the mean of t_1 is zero, we shall use this expression for writing down the moments of $(t/\sqrt{n})$ for degrees of freedom $n, n+2, n+4, \ldots$, and obtain the $2r^{\text{th}}$ moment of $t_1/\sqrt{n}$.

$$\text{Thus } \mu_{2r}(t_1/\sqrt{n}) = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \cdot \frac{\mathrm{B}((n/2)+j-r,\ r+\frac{1}{2})}{\mathrm{B}((n/2)+j,\ \frac{1}{2})}$$

$$\text{Hence } \mu_{2r}(t_1) = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!}\, n^r \cdot \frac{\mathrm{B}((n/2)+j-r,\ r+\frac{1}{2})}{\mathrm{B}((n/2)+j,\ \frac{1}{2})} \qquad (3)$$

It can be shown that the distribution of t_1 tends to the normal with mean zero and standard deviation unity as $n \to \infty$ for any value of λ. For, from (3),

$$\mu_{2r}(t_1) = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \; n^r \frac{\Gamma((n/2)+j-r)\;\Gamma(r+\frac{1}{2})}{\Gamma((n/2)+j)\;\Gamma(\frac{1}{2})}$$

$$= \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \; \frac{\Gamma(r+\frac{1}{2})}{\Gamma(\frac{1}{2})}$$

$$\frac{n^r}{((n/2)+j-1)\,((n/2)+j-2)\ldots.((n/2)+j-r)}$$

and $\dfrac{n^r}{((n/2)+j-1)\,((n/2)+j-2)\ldots.((n/2)+j-r)}$ tends to 2^r as n tends to ∞. Hence, owing to uniform convergence of the series, $\mu_{2r}(t_1)$ tends to

$$\frac{\Gamma(r+\frac{1}{2})}{\Gamma(\frac{1}{2})} \; 2^r \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} = \frac{\Gamma(r+\frac{1}{2})\,2^r}{\Gamma(\frac{1}{2})}$$

which is the $2r^{\text{th}}$ moment of a normal distribution with unit standard deviation. The odd moments being zero, we infer that the t_1-distribution tends to the normal as the degrees of freedom n become indefinitely large.

1·3 *Approximations to the distribution of* t_1.

The probability integral of t_1 is given by integrating the right side of (2) term by term, this being justified on account of uniform convergence of the series. To evaluate the probability integral, this process becomes elaborate as a large number of t-integrals have to be computed for a specified degree of accuracy. Similarly the determination of the percentage points of t_1 will be laborious. Hence an approximation to this distribution is considered, from which the probability integral and percentage points could be easily obtained.

As the probability density of t_1 is the sum of those of weighted t's, we might approximate the distribution of t_1 by a distribution $\sqrt{c}\;t$ having the same second and fourth order moments. Here $\sqrt{c}$ will be a scale factor and t will have ν degrees of freedom, ν being in general, fractional.

The expressions for $\mu_2(t_1)$ and $\mu_4(t_1)$ from (3) can be put into simpler forms for evaluation.

Thus $$\mu_2(t_1) = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} n \frac{B((n/2)+j-1,\ 1+\frac{1}{2})}{B((n/2)+j,\ \frac{1}{2})}$$

$$= \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \cdot \frac{n}{n+2j-2}$$

$$= \frac{e^{-\lambda/2}\lambda/2}{((n/2)-1)} F((n/2)-1,\ n/2;\ \lambda/2)$$

where

$$F(a,\ b;\ x) = 1 + \frac{a}{b}\frac{x}{1!} + \frac{a(a+1)}{b(b+1)}\frac{x^2}{2!} + \cdots$$

Since

$$e^{-x}F(a,\ b;\ x) = F(b-a,\ b;\ -x)$$

we get

$$\mu_2(t_1) = \frac{n/2}{((n/2)-1)} F(1,\ n/2;\ -\lambda/2)$$

$$= \frac{n/2}{((n/2)-1)} \left[1 - \frac{1}{n/2}(\lambda/2) + \frac{1}{(n/2)((n/2)+1)}(\lambda/2)^2 - \frac{1}{(n/2)((n/2)+1)((n/2)+2)}(\lambda/2)^3 + \cdots \right] \quad (4)$$

If $n/2$ is an integer, this sum of an infinite series can be written as a finite sum. Thus $\mu_2(t_1)$ is given by

$$\frac{n/2\ ((n/2)-2)!}{(\lambda/2)^{(n/2)-1}} \left[1 - (\lambda/2) + \frac{(\lambda/2)^2}{2!} - \cdots + \frac{(\lambda/2)^{(n/2)-2}}{((n/2)-2)!} - e^{-\lambda/2} \right] \quad (5)$$

when $n/2$ is even, and by

$$\frac{n/2\,((n/2)-2)!}{(\lambda/2)^{(n/2)-1}} \left[e^{-\lambda/2} - \left\{ 1 - \lambda/2 + \frac{\lambda/2)^2}{2!} - \cdots - \frac{(\lambda/2)^{(n/2)-2}}{((n/2)-2)!} \right\} \right] \quad (6)$$

when $n/2$ is odd.

Next,

$$\mu_4(t_1) = \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \; n^2 \; \frac{B((n/2)+j-2,\ 2+\frac{1}{2})}{B((n/2)+j,\ \frac{1}{2})}$$

$$= \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \; \frac{3n^2}{(n+2j-2)\,(n+2j-4)}$$

$$= 3(n/2)^2 \sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!} \left\{ \frac{1}{(n/2)+j-2} - \frac{1}{(n/2)+j-1} \right\}$$

$$= \frac{3(n/2)^2}{(n/2)-2} \; e^{-\lambda/2} F((n/2)-2,\ (n/2)-1;\ \lambda/2) - 3(n/2)\mu_2(t_1)$$

$$= \frac{3(n/2)^2}{(n/2)-2} \; F(1,\ (n/2)-1;\ -\lambda/2) - 3(n/2)\mu_2(t_1)$$

$$= \frac{3(n/2)^2}{(n/2)-2} \left[1 - \frac{\lambda/2}{(n/2)-1} + \frac{(\lambda/2)^2}{((n/2)-1)\,(n/2)} - \cdots \right] - 3(n/2)\mu_2(t_1)$$

The series in brackets can be expressed in terms of $\mu_2(t_1)$, using (4). Thus

$$\mu_4(t_1) = \frac{3n}{2(n-4)} [n - (n+\lambda-4)\mu_2(t_1)] \qquad .. \quad (7)$$

For even values of n which are small or moderately large, the expressions (5) and (6) contain only a few terms and so could be evaluated. When n is not even, $\mu_2(t_1)$ can be obtained from expression (4) using the first few terms and neglecting the others which are very small. For large values of n, even or odd, this form (4) is used to yield a good level of accuracy.

To compute the fourth moment of t_1, the value of $\mu_2(t_1)$ is substituted in (7).

Now the second and fourth moments of $\sqrt{c}t$ with ν degrees of freedom are

$$\frac{c\nu}{\nu-2} \text{ and } \frac{3c^2\nu^2}{(\nu-2)\ (\nu-4)} \qquad .. \quad (8)$$

So, to fit the $\sqrt{c}t$ distribution to that of t_1, we equate the expressions in (8) to $\mu_2(t_1)$ and $\mu_4(t_1)$ obtained above.
Thus

$$\left.\begin{aligned} \frac{c\nu}{\nu-2} &= \mu_2(t_1) \\ \frac{3c^2\nu^2}{(\nu-2)\quad(\nu-4)} &= \mu_4(t_1) \end{aligned}\right\} \qquad .. \quad (9)$$

After evaluating $\mu_2(t_1)$ and $\mu_4(t_1)$ for the given t_1-distribution, we solve the equations in (9) to obtain c and ν. The values of c and ν for $n = 6(1)\ 20,\ 30$ and 40 and $\lambda = 2(2)\ 20$ have been computed and given in auxiliary Table I. Interpolation may be made for intermediate values of λ.

1·4 *Evaluation of the probability integral and percentage points of* t_1.

On the basis of the approximation described in section 1·3, the probability integral $\int_{-\infty}^{T_1} p_n(t_1|\lambda)\,dt_1$ is approximately given by $\int_{-\infty}^{T_1/\sqrt{c}} p_\nu(t)\,dt$ in which ν and c have the values satisfying (9). This integral can be written as an Incomplete Beta Function $1 - \frac{1}{2} I_{\left(\frac{1+T_1^2}{c\nu}\right)^{-1}}(\nu/2, \frac{1}{2})$, and can be evaluated from the Incomplete Beta-Function Tables (K. Pearson, 1934).

The exact value of the probability integral given by the sum of the integrals of the terms of the series on the right side of (2), can be expressed as a series of weighted Incomplete Beta Functions,

$$\int_{-\infty}^{T_1} p_n(t_1 \mid \lambda)\,dt_1 = 1 - \frac{1}{2}\left\{\sum_{j=0}^{\infty} \frac{e^{-\lambda/2}(\lambda/2)^j}{j!}\, I_{\left(\frac{1-T_1^2}{n}\right)^{-1}}((n/2)+j, \tfrac{1}{2})\right\} \qquad (10)$$

Auxiliary Table I giving values of ν and $\sqrt{c}$ for

Degrees of freedom	Non-central									
	$\lambda = 2$		$\lambda = 4$		$\lambda = 6$		$\lambda = 8$		$\lambda = 10$	
n	ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$
6.	6·0997	·8613	6·3717	·7643	6·7955	·6944	7·3654	·6421	8·0462	·6011
7.	7·1192	·8792	1·4318	·7917	7·8974	·7261	8·4902	·6752	9·1875	·6343
8.	8·1300	·8927	8·4631	·8126	8·9478	·7508	9·5512	·7017	10·2487	·6614
9.	9·1351	·9034	9·4784	·8294	9·9710	·7710	10·5770	·7237	11·2706	·6844
10.	10·1355	·9121	10·4841	·8433	10·9787	·7880	11·5829	·7424	12·2707	·7041
11.	11·1375	·9193	11·4844	·8550	11·9770	·8024	12·5767	·7586	13·2577	·7214
12.	12·1516	·9255	12·4815	·8650	12·9693	·8150	13·5628	·7728	14·2364	·7367
13.	13·1347	·9306	13·4750	·8737	13·9578	·8260	14·5447	·7854	15·2099	·7503
14.	14·1323	·9352	14·4646	·8813	14·9439	·8357	15·5233	·7966	16·1802	·7625
15.	15·1297	·9392	15·4594	·8880	15·9286	·8444	16·4998	·8066	17·1481	·7735
16.	16·1270	·9427	16·4506	·8940	16·9126	·8522	17·4749	·8157	18·1149	·7836
17.	17·1241	·9458	17·4416	·8994	17·8956	·8592	18·4501	·8240	19·0811	·7927
18.	18·1213	·9486	18·4325	·9043	18·8775	·8656	19·4255	·8315	20·0750	·8012
19.	19·1184	·9511	19·4237	·9087	19·8617	·8714	20·3994	·8384	21·0130	·8089
20.	20·1156	·9534	20·4143	·9127	20·8493	·8768	21·3721	·8447	21·9795	·8160
30.	30·0916	·9682	30·3359	·9393	30·6978	·9128	31·1496	·8884	31·6777	·8659
40.	40·0761	·9759	40·2791	·9534	40·5893	·9325	40·9809	·9128	41·4471	·8944

the $\sqrt{c}\ t_\nu$ approximation to t_1, (n, λ).

parameter λ.

$\lambda = 12$		$\lambda = 14$		$\lambda = 16$		$\lambda = 18$		$\lambda = 20$	
ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$	ν	$\sqrt{c}$
8·8355	·5679	9·7017	·5401	10·6206	·5161	11·5749	·4951	12·5490	·4764
9·9675	·6005	10·8100	·5719	11·7017	·5471	12·6182	·5253	13·5655	·5060
11·0192	·6277	11·8456	·5988	12·7135	·5737	13·6128	·5516	14·5346	·5319
12·0320	·6510	12·8456	·6223	13·6974	·5971	14·5822	·5748	15·4870	·5548
13·0232	·6713	13·8253	·6428	14·6659	·6178	15·5367	·5955	16·4304	·5754
14·0012	·6893	14·7928	·6611	15·6232	·6363	16·4822	·6140	17·3657	·5940
14·9710	·7052	15·7532	·6776	16·5728	·6530	17·4215	·6309	18·2953	·6109
15·9356	·7196	16·7086	·6924	17·5180	·6681	18·3586	·6462	19·2220	·6264
16·8967	·7325	17·6605	·7058	18·4617	·6819	19·2926	·6603	20·1479	·6406
17·8560	·7443	18·6108	·7181	19·4037	·6945	20·2255	·6732	21·0728	·6537
18·8137	·7550	19·5599	·7293	20·3439	·7062	21·1579	·6851	21·9969	·6658
19·7715	·7648	20·5090	·7397	21·2836	·7169	22·0911	·6961	22·9214	·6771
20·7283	·7739	21·4578	·7493	22·2246	·7269	23·0230	·7064	23·8469	·6876
21·6770	·7823	22·4069	·7582	23·1666	·7361	23·9444	·7159	24·7727	·6974
22·6439	·7900	23·3565	·7664	24·1076	·7448	24·8903	·7249	25·6998	·7065
32·2656	·8450	32·9013	·8255	33·5793	·8074	34·2908	·7903	34·8069	·7719
41·9683	·8770	42·5414	·8606	43·1475	·8451	43·8068	·8304	44·4891	·8164

To evaluate the terms here, the Poisson terms $\frac{e^{-\lambda/2}(\lambda/2)^j}{j!}$ are taken from Molina's Tables (1947). Since these become very small for large values of j, a small number of terms taken from the beginning in (10), is sufficient to give accuracy to 2 or 3 decimal places.

Following this method, a few exact values are obtained and shown in Table II along with the approximate values based on the t-approximation. The agreement is seen to be very close.

TABLE II showing exact and approximate values of

$$\left[\int_{-\infty}^{T_1} p_n(t_1)\, dt_1 \right]$$

η	λ	T_1	Exact	Approximate
10	1·8	0·5	·7008	·7008
	1·8	1·0	·8489	·8489
	1·8	2·0466	·9750	·9750
	6	0·5	·7305	·7307
	6	1·0	·8845	·8847
	6	1·7347	·9750	·9751
20	1·8	0·5	·7002	·7007
	1·8	1·0	·8456	·8456
	1·8	1·9973	·9750	·9750
	6	0·5	·7169	·7171
	6	1·0	·8665	·8665
	6	1·8241	·9750	·9750
	10	0·5	·7313	·7305
	10	1·0	·8833	·8825
	10	1·6924	·9750	·9750

The percentage points of t_1 can be found approximately using the t-tables (Merrington, 1942) by interpolating for ν, the frac-

tional degrees of freedom in the appropriate percentage point tables, and then multiplying the interpolate by $\sqrt{c}$. Four-point Lograngian Interpolation may be used.

For comparison, the exact value of the integral $2\int_a^\infty p_n(t_1 \mid \lambda)\,dt_1$ where 'a' is the approximate 5% point is evaluated using (10), for a few values of n and λ, and shown in Table III. The closeness of the values to ·05 suggests that the approximation is very good.

TABLE III showing $2\int_a^\infty p(t_1)\,dt_1$, where a is the approximate 5% point of t_1.

n	λ	a	$2\int_a^\infty p(t_1)\,dt_1$,
10	1·8	2·0466	·0500
10	6	1·7347	·0498
10	10	1·5304	·0497
20	1·8	1·9973	·0500
20	6	1·8241	·0500
20	10	1·6924	·0500

The 5 per cent points of t_1 derived from the above approximation of t_1 by $\sqrt{c}t$ are calculated for $n = 6(1)20$, 30, 40 and $\lambda = 2(2)20$ and shown in Table IV. It is seen that when $\lambda = 0$, the values are those of the 5% t-points, and when $n = \infty$, they are the normal points, whatever be λ.

It has to be remembered that $\lambda = \Sigma a_i^2$ where $E(x_i) = a_i$ while Var $(x_i) = \text{Var}(\xi) = 1$. But if $\text{Var}(x_i) = \text{Var}(\xi) = \sigma^2$, $t_1 = \dfrac{\xi\sqrt{n}}{\sqrt{\Sigma x_i^2}}$ is distributed with $\lambda = \dfrac{\Sigma a_i^2}{\sigma^2}$.

TABLE IV

The 5% points of the t_1 distribution with n degrees of freedom and parameter λ

n \ λ	0	2	4	6	8	10	12	14	16	18	20
6.	2·447	2·099	1·844	1·652	1·503	1·385	1·288	1·208	1·141	1·083	1·033
7.	2·365	2·072	1·850	1·678	1·541	1·431	1·338	1·261	1·195	1·138	1·083
8.	2·306	2·053	1·856	1·700	1·574	1·469	1·381	1·307	1·242	1·186	1·137
9.	2·262	2·039	1·862	1·719	1·601	1·502	1·418	1·346	1·283	1·228	1·179
10.	2·228	2·029	1·867	1·735	1·624	1·530	1·450	1·380	1·319	1·265	1·217
11.	2·201	2·020	1·872	1·749	1·645	1·555	1·478	1·411	1·352	1·299	1·251
12.	2·179	2·014	1·877	1·761	1·663	1·578	1·503	1·438	1·380	1·329	1·282
13.	2·160	2·009	1·881	1·772	1·679	1·597	1·526	1·463	1·406	1·356	1·310
14.	2·145	2·004	1·885	1·782	1·693	1·615	1·546	1·485	1·430	1·381	1·336
15.	2·132	2·000	1·888	1·791	1·706	1·631	1·565	1·505	1·452	1·403	1·360
16.	2·120	1·997	1·891	1·799	1·717	1·646	1·581	1·524	1·472	1·424	1·381
17.	2·110	1·994	1·894	1·806	1·728	1·659	1·597	1·541	1·490	1·440	1·401
18.	2·101	1·992	1·897	1·813	1·738	1·671	1·611	1·556	1·507	1·461	1·420
19.	2·093	1·990	1·899	1·819	1·747	1·682	1·624	1·571	1·522	1·478	1·437
20.	2·086	1·988	1·901	1·824	1·755	1·692	1·636	1·584	1·537	1·494	1·454
30.	2·042	1·977	1·917	1·862	1·812	1·764	1·721	1·680	1·642	1·606	1·573
40.	2·021	1·972	1·927	1·884	1·844	1·806	1·770	1·736	1·704	1·674	1·645
∞	1·960	1·960	1·960	1·960	1·960	1·960	1·960	1·960	1·960	1·960	1·960

2. Applications of the t_1-distribution

2·1 *Test for equality of the means of two samples when they are non-homogeneous.*

Suppose there are two samples each containing n observations. Consider the hypothesis that a fraction f of each is drawn from a normal population and the rest drawn from another normal population having the same variance but a different mean. Each sample is then 'mixed' or non-homogeneous; such a situation will arise when the observations in each sample are taken by two observers, one of whom has a systematic bias, or when they are drawn from two strata, one differing from the other in the mean. The two sets of observations in each sample may not be identified and so separated. The well known two-sample t-test will not be applicable now and a modification will be considered involving the t_1-distribution. It is possible to test the above hypothesis if the difference in the standardised means* of the two populations is given. The problem is specified thus :—

Let the standardised means of m $(= nf)$ observations of the first sample be $\varrho_1 = \mu_1/\sigma$ and of m observations of the second be $\varrho_2 = \mu_2/\sigma$, while the standardised means of the remaining $(n-m)$ observations of the 1st and 2nd samples are $\varrho_1 + a = (\mu_1 + \delta)/\sigma$ and $\varrho_2 + a = (\mu_2 + \delta)/\sigma$, respectively.

The null hypothesis $H_0 : \varrho_1 = \varrho_2$ is equivalent to the hypothesis $\mu_1 = \mu_2$, since the variances are the same. The alternative hypothesis is $\varrho_1 \neq \varrho_2$, i.e., $\mu_1 \neq \mu_2$. It will be seen that a is given, as also $f = m/n$.

Suppose $\bar{x}_1$ and $\bar{x}_2$ are the means of the two samples, and

$$S_1^2 = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)^2 \text{ and } S_2^2 = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)^2$$

Then under H_0,

$$\begin{aligned} E\left(\frac{\bar{x}_1 - \bar{x}_2}{\sigma}\right) &= [\{m\varrho_1 + (n-m)(\varrho_1 + a)\} \\ &\quad - \{m\varrho_2 + (n-m)(\varrho_2 + a)\}]/n \\ &= 0 \end{aligned}$$

* A standardised mean is defined as the ratio of the mean to the standard deviation of a distribution.

and

$$\text{Var}\left(\frac{\bar{x}_1 - \bar{x}_2}{\sigma}\right) = \frac{2}{n}$$

Hence $(x_1 - x_2)$ is distributed as $N(0, \sqrt{(2/n)}\,\sigma)$

$$\text{Since } E\left(\frac{x_{1i} - x_1}{\sigma}\right) = \varrho_1 - \left(\varrho_1 + \frac{n-m}{n}a\right)$$

$$= -\frac{n-m}{n}a \text{ for } i = 1, \ldots m$$

and $$= \varrho_1 + a - \left(\varrho_1 + \frac{n-m}{n}a\right)$$

$$= \frac{m}{n}a \text{ for } i = m+1, \ldots n,$$

$\frac{S_1^2}{\sigma^2}$ is distributed as non-central χ^2 with $(n-1)$ degrees of freedom and non-central parameter

$$\lambda_1 = \left[\left(\frac{n-m}{n}\right)^2 m + \left(\frac{m}{n}\right)^2 (n-m)\right]a^2$$

$$= (n-m)\frac{mn}{n^2}a^2 = nf(1-f)a^2.$$

Similarly $\frac{S_2^2}{\sigma^2}$ is distributed as χ'^2 with $(n-1)$ degrees of freedom and parameter $\lambda_2 = nf(1-f)a^2$.

Since the samples are independent, $\frac{S_1^2 + S_2^2}{\sigma^2}$ is distributed as χ'^2 with $(2n-2)$ degrees of freedom and parameter $\lambda = 2nf(1-f)a^2$. .. (11)

Thus the ratio

$$u = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2 + S_2^2}{(n-1)n}}} \qquad .. \quad (12)$$

follows a t_1-distribution with $2(n-1)$ degrees of freedom and parameter λ given by (11).

It is seen that if $f = 1$ or $a = 0$, this u reduces to a t-ratio; for then the samples become homogeneous.

Hence to test the hypothesis H_0 ($\mu_1 = \mu_2$) as against alternatives of the kind $\mu_1 \neq \mu_2$, we refer u in (12) to the t_1-probability scale. Table IV may be used when the level of significance is 0·05. If the alternatives are one sided, clearly one tail of the t_1-distribution forms the critical region and so the tabled values would provide the test at 0·025 level.

We may next consider the case of samples which are unequal in size, but where the proportion of observations from each population, is the same. Let n_1 and n_2 be the number of observations of which a proportion f have standardised mean ϱ and $(1-f)$ have standardised mean $\varrho + a$.
It can be shown, as before, that the ratio

$$u = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2 + S_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad .. \quad (13)$$

follows a t_1-distribution with degrees of freedom $(n_1 + n_2 - 2)$ and non-central parameter

$$\lambda = (n_1 + n_2) f (1-f) a^2 \qquad .. \quad (14)$$

In case the fraction f is not a constant in the two samples, the expected value of the numerator in (13) is not zero, and so the distribution is not a t_1.

Illustration I.

Suppose there are two samples of 10 and 15 observations in which the means are $\bar{x}_1 = 15$, $\bar{x}_2 = 8$ and the sum of squares $S_1^2 = 440$ and $S_2^2 = 802$. It is known that one-fifth of them are rogue observations, but which they are cannot be identified, for otherwise they could be excluded. Further, let each of these rogue observations have a standardised mean which differs from that of the others by 1·2. To test the significance of the difference of the means, we assume a common variance and construct the statistic u in (13) which is here distributed as a t_1 with 23 degrees

of freedom and parameter $\lambda = (10 + 15)\,\frac{1}{6}\,(1 - \frac{1}{6})\,(1{\cdot}2)^2 = 5{\cdot}76$. Now the calculated value of u is $2{\cdot}\dot{3}$, and from Table IV, the 5% t_1-point for $n = 20$, $\lambda = 4$ is 1·901; for $n = 20$, $\lambda = 6$ is 1·824, for $n = 30$, $\lambda = 4$ is 1·917 and for $n = 30$, $\lambda = 6$ is 1·862. Therefore the two means are significantly different at the five per cent level of significance.

Before applying the t_1-test as described above, we might test for the assumption of equality of variances. The ratio $\dfrac{S_1^2/(n_1-1)}{S_2^2/(n_2-1)}$ is distributed as the ratio of two χ'^2 if the hypothesis is true. This distribution has been examined by K. Sundaresan (M.Sc. unpublished thesis, Madras University, 1951) and approximating both the numerator and denominator by χ^2's having the same first two moments [Patnaik, 1949], the test is approximately equivalent to an F-test.

2·2 *Confidence Interval for* $(\mu_1 - \mu_2)$.

When two independent samples of sizes n_1 and n_2 are drawn from two mixed normal populations whose means are μ_1 and $\mu_1+\delta$, and μ_2 and $\mu_2+\delta$, on the assumption of a common variance, it can be seen as in Section 2·1 that the ratio

$$\frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\left\{ \dfrac{S_1^2+S_2^2}{n_1+n_2-2}\left(\dfrac{1}{n_1}+\dfrac{1}{n_2} \right) \right\}^{\frac{1}{2}}}$$

is distributed as a t_1 with $(n_1 + n_2 - 2)$ degrees of freedom and parameter $\lambda = (n_1 + n_2) f (1 - f) a^2$.

We might use this distribution for finding the confidence limits of $(\mu_1 - \mu_2)$. Let $t_{1\alpha}$ be the $100\alpha\%$ point of t_1 with the degrees of freedom and λ given above. Then

$$P\left\{ -t_{1\alpha} \leqslant \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\left[\dfrac{S_1^2+S_2^2}{n_1+n_2-2}\left(\dfrac{1}{n_1}+\dfrac{1}{n_2}\right)\right]^{\frac{1}{2}}} \leqslant t_{1\alpha} \right\} = 1 - \alpha$$

Hence

$$P\left[\bar{x}_1 - \bar{x}_2 - t_{1\alpha} \left\{ \frac{S_1^2+S_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)\right\}^{\frac{1}{2}} \leqslant \mu_1 - \mu_2 \leqslant \bar{x}_1 - \bar{x}_2 + t_{1\alpha} \left\{ \frac{S_1^2+S_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)\right\} \right] = 1 - \alpha \quad .. \quad (15)$$

Since $t_{1\alpha}$ is less than t_α, the $100\alpha\%$ t-point with the same degrees of freedom, it follows that the confidence interval based on mixed samples is shorter than in the other case. This is as expected since more information is then given about the samples.

In illustration I of Section 2·1, the observed value of $\bar{x}_1 - \bar{x}_2 = 7$, of $\dfrac{S_1^2+S_2^2}{n_1+n_2-2}\left(\dfrac{1}{n_1}+\dfrac{1}{n_2}\right) = 3{\cdot}0$, and $t_{1(\cdot 05)}$ for 23 degrees of freedom and $\lambda = 5{\cdot}76$ is nearly 1·84. Hence the 95% confidence interval of $(\mu_1 - \mu_2)$ is $(7 - 1{\cdot}84\times 3,\ 7+1{\cdot}84\times 3)$, that is, $(1{\cdot}48,\ 12{\cdot}52)$.

2·3 *The test of equality of means when the variances are unequal.*

Suppose it cannot be assumed that the variances of the two populations in Section 2·1 are the same, i.e., suppose $\theta = \dfrac{\sigma_1^2}{\sigma_2^2} \neq 1$. Then the two sample t_1-test of the equality of the population means, using the statistic

$$u = \frac{\bar{x}_1 - \bar{x}_2}{\left\{\dfrac{S_1^2+S_2^2}{n_1+n_2-2}\left(\dfrac{1}{n_1}+\dfrac{1}{n_2}\right)\right\}^{\frac{1}{2}}} \quad \text{in (13)}$$

breaks down. Following Welch's procedure for the two-sample t-test when $\theta \neq 1$ (Biometrika, *29*, 1938), similar results can be derived for the two-sample t_1-test for mixed populations when $\theta \neq 1$.

Now $\dfrac{x_1 - \bar{x}_2}{\sqrt{\dfrac{\sigma_1^2}{n_1}+\dfrac{\sigma_2^2}{n_2}}}$ is distributed as a normal deviate ξ, $N(0, 1)$ and $(S_1^2 + S_2^2)$ is distributed as $(\sigma_1^2 \chi_1'^2 + \sigma_2^2 \chi_2'^2)$. Hence the statistic u in (13) which can be written as

$$\frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\dfrac{\sigma_1^2}{n_1}+\dfrac{\sigma_2^2}{n_2}}} \Bigg/ \left\{\frac{S_1^2+S_2^2}{n_1+n_2-2}\left(\frac{n_1+n_2}{n_1\sigma_2^2+n_2\sigma_1^2}\right)\right\}^{\frac{1}{2}} \text{ is of the form}$$

$$\frac{\xi}{b_1\chi_1'^2 + b_2\chi_2'^2} \qquad \ldots \quad (16)$$

where $$b_1 = \frac{\sigma_1^2}{n_1+n_2-2}\left(\frac{n_1+n_2}{n_1\sigma_2^2+n_2\sigma_1^2}\right)$$

and $$b_2 = \frac{\sigma_2^2}{n_1+n_2-2}\left(\frac{n_1+n_2}{n_1\sigma_2^2+n_2\sigma_1^2}\right) \quad \ldots (17)$$

The denominator in (16) can be approximated by a χ'^2-distribution, so that the ratio u would follow at t_1-distribution. As however, the t_1-distribution itself has to be approximated by a t-distribution for finding the probability integral, it appears reasonable to straightaway approximate $(b_1\chi_1'^2 + b_2\chi_2'^2)$ by a χ^2-distribution, say $g\chi^2$ with ν degrees of freedom.

Equating the first two moments of $(b_1\chi_1^2 + b_2\chi_2^2)$ and $g\chi_\nu^2$, we get

$$b_1(n_1-1+\lambda_1) + b_2(n_2-1+\lambda_2) = g\nu$$

and $$\ldots (18)$$

$$2b_1^2(n_1-1+2\lambda_1) + 2b_2^2(n_2-1+2\lambda_2) = 2g^2\nu$$

From these,

$$\nu = \frac{\{b_1(n_1-1+\lambda_1)+b_2(n_2-1+\lambda_2)\}^2}{b_1^2(n_1-1+2\lambda_1)+b_2^2(n_2-1+2\lambda_2)}$$

$$= \frac{\{\sigma_1^2(n_1-1+\lambda_1)+\sigma_2^2(n_2-1+\lambda_2)\}^2}{\sigma_1^4(n_1-1+2\lambda_1)+\sigma_2^4(n_2-1+2\lambda_2)}$$

$$= \frac{\{\theta(n_1-1+\lambda_1)+n_2-1+\lambda_2\}^2}{\{\theta^2(n_1-1+2\lambda_1)+n_2-1+2\lambda_2\}} \quad \ldots (19)$$

and

$$\nu g = b_1(n_1-1+\lambda_1)+b_2(n_2-1+\lambda_2)$$

$$= \{\sigma_1^2(n_1-1+\lambda_1)+\sigma_2^2(n_2-1+\lambda_2)\}\frac{(n_1+n_2)}{(n_1\sigma_2^2+n_2\sigma_1^2)(n_1+n_2-2)}$$

$$= \{\theta(n_1-1+\lambda_1)+n_2-1+\lambda_2\}\frac{(n_1+n_2)}{(n_1+\theta n_2)(n_1+n_2-2)} \quad (20)$$

Thus the scale factor g and the degrees of freedom ν can be expressed in terms of n_1, n_2, λ_1, λ_2 and θ. So (u) of (13) is distributed approximately as $\dfrac{\xi}{\sqrt{g\chi_\nu^2}} = \dfrac{\xi\sqrt{\nu}}{\chi_\nu\sqrt{g\nu}}$. That is, $\sqrt{g\nu}\ u$ is distributed as $\dfrac{\xi\sqrt{\nu}}{\chi_\nu}$ or as a t with ν degrees of freedom.

Since the above distribution involves the value θ, we cannot use it to test the hypothesis regarding the means. But by considering particular values of θ, we can judge how far the test based on the assumption that $\theta = 1$ is likely to be valid.

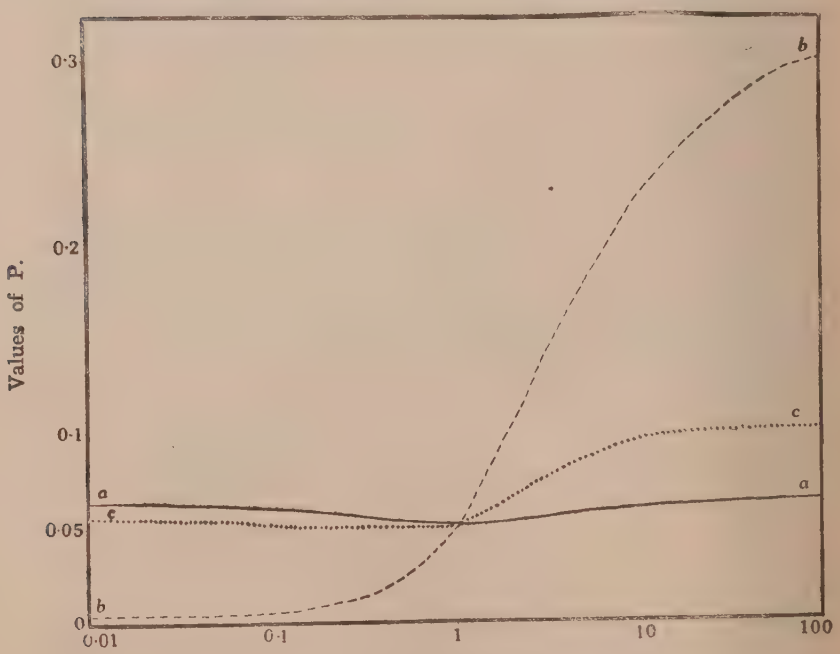
Taking the case of equal samples with $n_1 = n_2 = 10$, $\lambda_1 = \lambda_2 = 2$ and the significance level $\alpha = \cdot 05$, we find from Table IV that the 5% t_1-value for $n = 18$, $\lambda = 4$ is $T_1 = 1 \cdot 897$. The value of the integral $P = 2\int_{T_1}^{\infty} p(u/\theta)\,du$ gives the true level of significance. On the basis of the above approximation, this is $2\int_{T_1\sqrt{g\nu}}^{\infty} p_\nu(t)\,dt$ in which ν and $g\nu$ are given by (19) and (20).

For a specified value of θ, this probability $P\{|u| > 1 \cdot 897\}$ can be obtained using the Incomplete Beta Function Tables. P is similarly obtained for a case of two unequal samples with $n_1 = 5$, $n_2 = 15$ and $\lambda_1 = 1$, $\lambda_2 = 3$. The following table gives the values of P in the two cases for $\theta = \cdot 01$, $\cdot 1$, 1, 10 and 100.

n_1	n_2	λ_1	λ_2	θ	$P\{\lvert u\rvert > 1 \cdot 897$ the 5% point of $t_1\}$
10	10	2	2	0·01	·064
				0·1	·060
				1·0	·05
				10·0	·060
				100·0	·064
5	15	1	3	0·01	·003
				0·1	·005
				1·0	·05
				10·0	·229
				100·0	·302

These values are plotted in Figure I.. The line (a) corresponding to $n_1 = 10$, $n_2 = 10$, $\lambda_1 = \lambda_2 = 2$ does not deviate much from the horizontal at $P = 0 \cdot 05$ and we may conclude that the test based on the assumption of equal variances is not much in error. In case (b) for $n_1 = 5$, $n_2 = 15$, $\lambda = 1$, $\lambda_1 = 3$, the test based on the assumption that $\theta = 1$ is not satisfactory, when actually $\theta \neq 1$. For $\theta < 1$, the test is very conservative, but for $\theta > 1$ it may err very seriously in the wrong direction. Therefore, for samples of equal size, there is not a serious likelihood of error when testing for the difference of means treating the parent variances as equal. When the samples are of unequal size, this test may be replaced by an alternative test.

Fig. 1. Showing the Values of P for different values of θ.



— *a*: $n_1 = n_2 = 10$, $\lambda_1 = \lambda_2 = 2$; $P\{|u| > t_1 \ (18, 4)\}$
— - *b*: $n_1 = 5$, $n_2 = 15$, $\lambda_1 = 1$, $\lambda_2 = 3$; $P\{|u| > t_1 \ (18, 4)\}$
.... *c*: $n_1 = 5$, $n_2 = 15$, $\lambda_1 = 1$, $\lambda_2 = 3$; $P\{|v| > t_1 \ (18, 4)\}$

2·4 *A modified test for unequal variances.*

Consider the ratio

$$v = \frac{\bar{x}_1 - \bar{x}_2}{\left\{ \frac{S_1^2}{n_1(n_1-1)} + \frac{S_2^2}{n_2(n_2-1)} \right\}^{\frac{1}{2}}} \quad .. \quad (21)$$

where as before $S_1^2 = \sum_{i=1}^{n_1} (\bar{x}_{1i} - \bar{x}_1)^2$ and $S_2^2 = \sum_{i=1}^{n_2} (\bar{x}_{2i} - \bar{x}_2)^2$.

It will be shown that in cases where $\theta = \sigma_1^2/\sigma_2^2$ differs greatly from unity, this ratio v can be used instead of the u-criterion of (13).

v can be written as

$$\frac{\bar{x}_1 - \bar{x}_2}{\left\{ \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right\}^{\frac{1}{2}}} \div \left\{ \frac{\frac{S_1^2}{n_1(n_1-1)} + \frac{S_2^2}{n_2(n_2-1)}}{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} \right\}^{\frac{1}{2}} = \frac{\xi}{\sqrt{w}}$$

where ξ is a normal deviate $N(0.1)$, and w is the sum of two weighted χ'^2 with degrees of freedom $(n_1 - 1)$, $(n_2 - 1)$ and parameters λ_1, λ_2 respectively.

i.e., $w = A\chi_1'^2 + B\chi_2'^2$ .. (22)

$$\left.\begin{aligned} \text{where } A &= \frac{\sigma_1^2}{n_1(n_1-1)} \Big/ \left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right) \\ \text{and } B &= \frac{\sigma_2^2}{n_2(n_2-1)} \Big/ \left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right) \end{aligned}\right\} \quad .. \quad (23)$$

Approximating the distribution of w by a χ^2-distribution with m degrees of freedom, multiplied by a scale-factor h, i.e., by $h\chi_m^2$, and equating the first two moments of w and $h\chi_m^2$, we get expressions for m and mh, using (23). Thus

$$m = \frac{\{A(n_1 - 1 + \lambda_1) + B(n_2 - 1 + \lambda_2)\}^2}{A^2(n_1 - 1 + 2\lambda_1) + B^2(n_2 - 1 + 2\lambda_2)}$$

$$= \frac{\left\{ \frac{(n_1-1+\lambda_1)\theta}{n_1(n_1-1)} + \frac{(n_2-1+\lambda_2)}{n_2(n_2-1)} \right\}^2}{\left\{ \frac{(n_1-1+2\lambda_1)\theta_1^2}{n_1^2(n_1-1)^2} + \frac{(n_2-1+2\lambda_2)}{n_2^2(n_2-1)^2} \right\}}$$

and

$$mh = A(n_1-1+\lambda_1) + B(n_2-1+\lambda_2)$$

$$= \frac{\left\{ \frac{(n_1-1+\lambda_1)\theta}{n_1(n_1-1)} + \frac{n_2-1+\lambda_2}{n_2(n_2-1)} \right\}}{\left\{ \frac{\theta}{n_1} + \frac{1}{n_2} \right\}} \qquad .. \quad (24)$$

Thus v is approximately distributed as $t/\sqrt{hm}$ having m degrees of freedom.

To show that the test based on referring the statistic v in (21) to the t_1-scale is better than that based on u in (13), for samples of unequal size, we compare the probabilities of u and v exceeding $t_{1\alpha}$, the $\alpha\%$ point of t_1. The values of $P\{|v| > 1{\cdot}897\}$ are calculated using the approximate t-distribution of v given above for the case $n_1 = 5$, $n_2 = 15$, $\lambda_1 = 1$, $\lambda_2 = 3$, $\alpha = {\cdot}05$ and plotted in Fig. I. The dotted line (c) passing through them does not deviate from $P = 0{\cdot}5$ as much as the curve (b) corresponding to the use of statistic u.

Hence if it is known that $\sigma_1 = \sigma_2$, then u is a better, more sensitive criterion than v; but if it is suspected that σ_1 and σ_2 differ greatly, it is safer to use the statistic v for samples of unequal size.

I thank Prof. P. B. Patnaik for his guidance during the course of my investigations.

REFERENCES

Molina, E. C. (1947) *Tables of Poisson's Exponential Limit.* D. Van Nostrand Company, New York.

Merrington, M. (1942) Table of precentage-points of the t-Distribution *Biometrika*, **32**, 300.

Patnaik, P. B. (1949) The Non-central χ^2 and F-Distributions and their applications. *Biometrika*, **36**, 202.

Pearson, K. (1934) *Tables of the Incomplete Beta Function*, University Press, Cambridge.

J. Madras Univ., B, No. 2, pages 273-278, 1954

A Characterization for Complete Boolean Algebras[1]

BY

V. K. BALACHANDRAN

Department of Mathematics, University of Madras, Madras-5.

(Received for publication, May 5, 1954)

ABSTRACT

A study is made of the ideal of elements of a lattice with product-complement zero (or sum-complement one). Some properties relating to distributive lattices and Boolean algebras are obtained as particular cases.

INTRODUCTION

In this note we first study some properties of the subsets π_a, π_μ[2] of a lattice L (with 0 and 1) comprising respectively the elements with product-complement [4; p. 40] 0, and those with sum-complement 1. It is to be noted here that these subsets are defined irrespective of whether L is closed for product-complements or sum-complements. In case L is a distributive lattice, an interesting connexion (Theorem (7)) can be established between π_a or π_μ and the last-residue class of ideals [1] of L.

We next obtain, in terms of π_a, π_μ, a sufficient condition (Theorem (10)) for a complete, distributive lattice L to be closed for sum-complements (or product-complements) which leads to a new characterization for complete Boolean algebras—the main result of the paper (Theorem (12)).

1. Most of the results of this note were included in the thesis of the author accepted by the Madras University for the award of the Ph.D. Degree (1951).

2. These were first introduced and studied for the distributive lattice by Vaidyanathaswamy [3] (numbers in square brackets refer to References given at the end).

THE GENERAL LATTICE

It follows immediately from the definition of π_a that an element a in it is characterized by the property

(1) $ax = 0 \longrightarrow x = 0$[3].

Hence if $a\varepsilon\pi_a$ and $b \geqslant a$, then obviously $b\varepsilon\pi_a$. Again if $a, b\varepsilon\pi_a$ then, $abx = 0 \longrightarrow bx = 0$ (since $a\varepsilon\pi_a$) and this $\longrightarrow x = 0$ (since $b\varepsilon\pi_a$); i.e., $ab\varepsilon\pi_a$. Thus

(2) **π_a is an α-ideal; dually π_μ is a μ-ideal.**

The ideal π_a (and dually π_μ) can also be characterized thus:

(3) *Theorem. π_a is identical with the set (y) of elements of the form $y = a + \acute{a}$, where a is any element of L whose product-complement $\acute{a}$ exists (here it is not assumed that L is closed for product-complements); (and dually π_μ).*

Proof. Let a be an element of L such that the product-complement $\acute{a}$ exists. If x be such that $(a + \acute{a})x = 0$, then $ax \leqslant (a + \acute{a})x = 0$, or $ax = 0$; similarly $\acute{a}x = 0$. From the first relation we have, by definition of $\acute{a}$, $x \leqslant \acute{a}$. Hence $x = \acute{a}x = 0$, i.e., $a + \acute{a}\varepsilon\pi_a$. On the other hand if $a\varepsilon\pi_a$, then since $\acute{a} = 0$, $a = a + \acute{a}$. Q.E.D.

If L is complemented then for each element a there exists b with $a + b = 1$, $ab = 0$. Hence if $y = (a + \acute{a})\varepsilon\pi_a$, it is clear that $b \leqslant \acute{a}$ (since $ab = 0$ and $\acute{a}$ is product-complement of a). Therefore $y = a + \acute{a} \geqslant a + b = 1$, or $y = 1$. Thus

(4) *Corollary. The ideal π_a of a complemented lattice (in particular of a Boolean algebra) L consists of the element 1 alone, or $\pi_a = O_a$ (O_a here denoting the "zero" of the complete lattice L_a of all α-ideals of L); (dually $\pi_\mu = O_\mu$).*

As an element of the lattice L_a, the ideal π_a can be expressed thus:

(5) *Theorem. π_a is the product πM_a of all maximal α-ideals M_a of L; (dually π_μ).*

3. For lattice-theoretic notations and definitions we follow closely [4, chpt. 3]; the p.o. relation will be here denoted by '$\leqslant$' (or '$\geqslant$').

4. "α-ideal" and "μ-ideal" are the same as "dual ideal" and "ideal" in the terminology of some writers.

We recall that an α-ideal $A_a \neq 1_a$ is called *maximal* if it is properly contained in no α-ideal except 1_a (i.e. the whole lattice). *Proof.* First we show: $M_a \supset \pi_a$. If $a \varepsilon \pi_a$, $a \bar{\varepsilon} M_a$,† then $M_a + P_a(a)^5 = 1_a$ since M_a is maximal. Hence $ma = 0$ for some $m \varepsilon M_a$; since $a \varepsilon \pi_a$, $m = 0$ whence $M_a = 1_a$ contradicting the fact that M_a is maximal. Consequently $M_a \supseteq \pi_a$ and so also $\pi M_a \supset \pi_a$.

Next if $a \varepsilon \pi_a$, there exists an element b with $ab = 0$, $b \neq 0$; by Zorn's lemma there exists a maximal α-ideal $M_a^* \supset P_a(b)$; M_a^* cannot contain a since $ab = 0$. Therefore $\pi M_a = \pi_a$. Q.E.D.

The Distributive Lattice

Henceforward we assume that L is a distributive lattice with 0 and 1. In this case there is the important concept of the last-residue class (or *l.r.c.*) of an α- (or μ-) ideal A (for definition and properties of the *l.r.c.*, see Krishnan [1]). An element $b \varepsilon$ (*l.r.c.* of an α-ideal A_a), if and only if, for some $a \varepsilon A_a$, $ba = 0$; and dually for the *l.r.c.* of a μ-ideal. The *l.r.c.* of an α-ideal is a μ-ideal and vice-versa.

It is clear from (1) that

(6) *π_a is the largest α-ideal whose l.r.c. is O_μ; (dual result for π_μ).*

The ideal π_a (or π_μ) stands in a significant relation to *l.r.c.* of an arbitrary α- (or μ-) ideal; before we state this we shall find it convenient to introduce some definitions and make a few preliminary remarks. The set $(A_a)_c$ of element $y \leqslant$ every element of an α-ideal A_a is a μ-ideal called the cut-complement of A_a; dually, if A_μ is a μ-ideal the cut-complement $(A_\mu)_c$ of A_μ (which is an α-ideal) is the set (y) of all elements $y \geqslant$ every element of A_μ. An α- (or μ-) ideal A is called comprincipal if it is the product of a family of principal α- (or μ-) ideals. A is comprincipal, if and only if, it is the cut-complement of its cut-complement, i.e., $A = A_{cc}$. Since for any ideal A, $A_c = A_{ccc}$ the cut-complement A_o is alway a comprincipal ideal. Also in a complete lattice every comprincipal ideal is principal. All the preceding concepts and results are due to Vaidyanathaswamy [2 & 3].

5. Denotes the principal α-ideal correrponding to a, i.e., the set (x) of elements $x \geqslant a$.

† $\bar{\varepsilon}$ stands for "is not an element of".

Now we may prove :

(7) *Theorem. Let* A_a *be an* α*-ideal and* $B_\mu = l.r.c.$ *of* A_a. *Then the ideal-product* $A_a . (B_\mu)_c \subset \pi_a$; (*and dually for a* μ*-ideal* A_μ).
Proof. For, if possible let $a \varepsilon A_a$, $a \varepsilon (B_\mu)_c$, $a \varepsilon \pi_a$. Since $a \varepsilon \pi_a$, we can find an element $b (\neq 0)$ such that $ab = 0$. It follows that $b \varepsilon B_\mu$. Since $a \varepsilon (B_\mu)_c$, $b \varepsilon B_\mu$, it results by definition of $(B_\mu)_c$ that $a \geqslant b$. Hence $b = ab = 0$, contradicting the choice of b. Thus the theorem is proved. Q.E.D.

(8) *Corollary. Let* $\Sigma_\mu = l.r.c.$ *of* π'_a; *then* $\pi_a'' = (\Sigma_\mu)_c$. *Hence* π_a'' *is comprincipal.*

(Here prime (′) signifies product-complementation in the complete lattice L_a of all α-ideals of L; see [4; p. 50, § 12.7]).
Proof. By the above theorem we have $\pi'_a . (\Sigma_\mu)_c \subset \pi_a$. On multiplying both sides of the last relation by π'_a we obtain $\pi'_a . (\Sigma_\mu)_c = O_a$ so that $(\Sigma_\mu)_c \supset \pi_a''$. But $\pi_a'' \subset (\Sigma_\mu)_c$ whence $\pi''_a = (\Sigma_\mu)_c$. The last inequality was only a particular case of the following general result :

(9) *The product-complement of an ideal is contained in the cut-complement of its l.r.c.* For, in fact if A_a be an α-ideal and $b \varepsilon B_\mu = l.r.c.$ of A_a, then $ba = 0$ for some $a \varepsilon A_a$. Let $x \varepsilon A'_a$ so that $x + a = 1$. Hence $b = b(x + a) = bx + ba = bx$ (since $ba = 0$) or $b \leqslant x$. Hence $A'_a \subset (B_\mu)_c$. Q.E.D.

By combining the results (7) and (9) we obtain :
(10) *Theorem. If* $\pi_a = O_a$, *then every normal* α*-ideal* A_a *of* L *is comprincipal being the cut-complement of its l.r.c.;*[6] *if in addition* L *is complete,* L *is closed for sum-complements.*
(*And dually*).

(A_a is called *normal* if $A_a = A_a''$, prime having same significance as in (8)).

Proof. For, by (7), $A'_a . (B_\mu)_c = O_a$ where $B_\mu = l.r.c.$ of A'_a. It follows that $(B_\mu)_c \subset A_a''$. But by (9), $A_a'' = (A'_a)' \subset (B_\mu)_c$. Hence $A_a = A_a'' = (B_\mu)_c$, proving the first part.

6. This part is equivalent to the dual of the *corollary* in [3; p. 381]; compare the proof.

To prove the second part, assume now that L is also complete; let $a \varepsilon L$. By the first part (proved) it results that $P_a'(a)$ is com-principal, and hence principal since L is complete. Thus $P_a'(a) = P_{\bar{a}}$ (say) and it is easy to see that $\bar{a}$ is the sum-complement of a. That is, L is closed for sum-complements. Q.E.D.

(11) *Remarks.* The second part of (10) can also be proved directly, without recourse to the first part, as follows. Let $\bar{a}$ denote the product πb of all elements b with $a + b = 1$. If we can show $a + \bar{a} = 1$, then it would clearly follow that $\bar{a}$ is the sum-complement of a. For proving this, we note that if $a + \bar{a} \neq 1$ then we could choose $x \neq 0$ with $(a + \bar{a})x = 0$ (since $\pi_a = O_a$) so that $xa = x\bar{a} = 0$. Hence $x = x(a + b) = xa + xb = xb$ (since $xa = 0$) or $x \leqslant b$, and so $x \leqslant \pi b = \bar{a}$, whence $x = x\bar{a} = 0$ which is a contradiction. Hence $a + \bar{a} = 1$, and the required result follows.

Characterization of the complete Boolean algebra

From the last result (10) we deduce the

(12) *Theorem. In order that a complete, distributive lattice L be a complete Boolean algebra, it is necessary and sufficient that the ideals π_a, π_μ be zero ideals $\pi_a = O_a$; $\pi_\mu = O_\mu$.*

Proof. That the conditions are "necessary" follows from (4).

For proving their "sufficiency", assume that L is a complete, distributive lattice with $\pi_a = O_a$, $\pi_\mu = O_\mu$. Since L is complete and $\pi_\mu = O_\mu$, it results by (10) that L is closed for product-complements. Let $a \varepsilon L$, then $a + \acute{a} \varepsilon \pi_a$ ((3)). Therefore $a + \acute{a} = 1$, since $\pi_a = O_a$ by hypothesis; also $a\acute{a} = 0$. Thus L is complemented, and hence a Boolean algebra. Q.E.D.

(13) *Remark.* (i) Now there exist non-distributive, complemented and complete lattices L (for instance, the "projective geometries"); here we have always $\pi_a = O_a$, $\pi_\mu = O_\mu$ by virtue of (4). Therefore the condition "distributive" cannot be omitted from the hypothesis on L in (12) if the conclusion therein is to hold.

(ii) Let R be an uncountable set. Denote by $L(R)$ the following collection of subsets of R:

(a) All finite subsets F (including the null-set φ) and their complements $(R—F)$;

(b) all countably infinite subsets of R.

It is easy to verify that $L(R)$ is a distributive lattice which is not complete. If $A \neq \varphi$ be an element of $L(R)$, $A \supset$ some $F \neq \varphi$ and so $A \cup (R-F) = R$, $(R-F)$ $(\neq R)$ $\varepsilon L(R)$. Hence $\pi_\mu = O_\mu$. Again if $A \neq R$, $(R-A) \supset$ some $F(\neq \varphi) \varepsilon L(R)$, and $A \cap F = \varphi$ hence $\pi_a = O_a$. Thus in $L(R)$, the conditions of (12) *viz.*, $\pi_a = O_a$, $\pi_\mu = O_\mu$, are fulfilled; however $L(R)$ is not a Boolean algebra (since complements of *countably* infinite subsets do not exist), thereby showing that in (12) the hypothesis of completeness of L cannot be relaxed.

(14) *Remark.* Characterizations similar and closely related to (12) have been previously given by the author, for the Boolean algebra and the complete atomic Boolean algebra (of all subsets of some set R). See Theorem 10 (*Ideals of the distributive lattice*, Jour. Ind. Math. Soc., **12** (1948), pp. 49-56) and Theorem B (*A Characterization of $\Sigma\triangle$-rings of subsets*, to appear in the Fundamenta Mathematicae **41** (1954)). See also the paper of Tadashi Michiura (Jour. Osaka Inst. Sci. & Tech. Vol. **1** (1949)) for other related characterizations of Boolean algebras.

REFERENCES

Krishnan, V. S. (1942) *The problem of the last-residue class in the distributive lattice, Proc. Indian Acad. Sci.* A. **16**: 176-190.

Vaidyanathaswamy, R. (1941) *The ideal theory of the partially ordered set, Proc. Indian Acad. Sci.* A. **13**: 94-99.

—— (1947) *On the lattice of open sets of a topological space. Ibid.* **16**: 379-386.

—— (1941) *Treatise on set-topology.* Published by the author, Madras.

J. Madras Univ., B, XXIV, No. 2, pages 279-294, 1954

Kinetics of Reactions between Chloride Radicals from Photo-excited Ion-pair $Fe^{+3}Cl^{-}$ and Vinyl Monomers in Aqueous Solution

BY

M. SANTHAPPA

University Physical Chemistry Laboratory, Madras-25.

(Received for publication, June 3, 1954)

ABSTRACT

Using the System, Ion-pair $Fe^{3+}Cl^{-}$ Vinyl monomer, in aqueous solution a new method of photo-polymerization of vinyl monomers is described. Light absorption by the photochemically active ion-pair $Fe^{+3}Cl^{-}$, leads to an electron transfer reaction involving reduction of the cation and oxidation of Cl^{-} to a free radical Cl which initiates polymerization. Kinetics of the reaction were followed by a study of the dependence of (a) light absorption fraction by the ion-pair, (b) light intensity, (c) concentration of monomer, (d) initially added ferrous and (e) quantum yields with regard to ferrous production and monomer disappearance upon (i) Rate of ferrous ion production, (ii) overall rate of Polymerization and (iii) chain-length of polymers. A prima facie reaction scheme was put forward. Examination of the experimental results in the light of the suggested scheme revealed that Cl radicals initiated polymerization and recombination of the active chain endings terminated Polymerization.

Rabinowitch and Stockmayer (1942) in their investigation on the ferric 'association' or 'ion-pair' complexes indicated that a solution of ferric chloride contained in addition to the neutral species $Fe(Cl)_3$, the ion pairs, $Fe^{3+}OH^{-}$, $Fe^{3+}Cl$, $Fe^{3+}Cl_2^{2-}$, $Fe^{3+}Cl_3^{3-}$, $Fe^{3+}Cl_4^{4-}$, $Fe^{3+}Cl_5^{5-}$, $Fe^{3+}Cl_6^{6-}$, etc. The yellow-green-brown colours of ferric chloride solutions were attributed to the presence of one or all the ion pairs. They interpreted the absorption spectra of $Fe^{3+}X^{-}$ (X = OH, Halide ion, etc.) as electron transfer spectra $Fe^{3+}X^{-} \xrightarrow{h\nu} Fe^{2+}X$, and the difference in the maxima of any two spectra corresponded to the difference in the electron affinities plus solvation energies of the respective anions. Rabinowitch (1942) therefore predicted occurrence of free radicals

or atoms during irradiation of aqueous ferric halide solutions. Evans and Uri (1949) showed that such free radicals initiated polymerization of Vinyl compounds. Evans, Santappa and Uri (1951) have briefly reported on the polymerization of Vinyl compounds in aqueous solution. This paper (Santappa, 1951) presents a detailed Kinetic behaviour of the ion-pair $Fe^{3+}Cl^{-}$ as a photosensitizer in the polymerization of vinyl monomers, chiefly methylmethacrylate, acrylonitrile and to some extent methacrylic acid.

Experimental

Optical arrangements:—The light source was a 250 watt high pressure B.T.H. mercury vapour lamp, the size of the arc being $3 \cdot 75$ mm. $\times$ $1 \cdot 5$ mm. The beam was rendered parallel by a condenser lens and then passed through suitable filters (1946) to isolate 313 mμ or 365 mμ. The monochromatic light beam was then used to irradiate the system $Fe^{3+}Cl^{-}$ (Ferric perchlorate + perchloric acid + hydrochloric acid) and vinyl monomer contained in a cell (capacity 75 ml, 50 mm. diameter and 46 mm. optical depth) which was mounted in a thermostat at $25 \pm 0 \cdot 1°$ C.

Purity of reagents:—Ferric perchlorate was prepared from precipitated brown ferric oxide and perchloric acid. Monomers were purified after removal of stabilizers by repeated distillation in an atmosphere of nitrogen. Feiser's (1924) solution was used for deoxygenating nitrogen which was used to deaerate the solutions before irradiation.

Estimations and determinations:—Ferric ion concentration was determined by Zimmer Mann-Reinhardt standard procedure. Ferrous ion (dFe^{+2}/dt) was determined colorimetrically with-O-Phenanthroline in Hilger Spekkar Colorimeter. Rate of monomer disappearance (dM/dt) was determined either by the weight of the purified and dried polymer or by the determination of monomer concentration before and after irradiation of the solution. Chain lengths of methyl methacrylate polymers (n) were determined viscometrically according to Baxendale, ByWater & Evan's (1946) method. Light absorption fraction (k_{ε}) by the complex $Fe^{3+}Cl^{-}$ could be calculated (1954) or measured spectrophotometrically. The lamp output or intensity of light (I) was determined actinometrically (Bowen, 1946) using uranium oxalate solution. Variation of light intensity was achieved by using an Iris

diaphragm in front of the lamp. Concentration of methyl methacrylate or methacrylic acid (M) was determined by bromine addition and after adding potassium iodide, titration against standard sodium thiosulphate.

Experimental Results:—(i) Light Absorption fraction (k_ε) by the ion pair: k_ε and dFe/dt. The concentration of $Fe^{3+}Cl^-$ and therefore the value of k_ε depends on the equilibrium $Fe^{3+}Cl^- + OH^- \rightleftharpoons Fe^{3+}Cl^- + OH^-$; in other words k_ε is dependent on ferric ion concentration. Table 1 gives variation k_ε with $[Fe^{3+}]$ as well as variation of dFe^{+2}/dt and dM/dt with k_ε.

TABLE 1.

Data for k_ε and dFe^{+2}/dt; [Methylmethacrylate] = 0·1 M; [HCl] = 0·05N; Time of irradiation = 1·00 hr.;

I, Intensity of light = $6{\cdot}5 \times 10^{-5}$ N$h\nu$/hr.

Data for k and dM/dt; [Methylmethacrylate] = 0·08 M;

I = $3{\cdot}8 \times 10^{-5}$ N$h\nu$/hr.

$[Fe^{3+}]$	k_ε	k^1_ε	dFe^{2+}/dt (moles/hr) $\times 10^6$	dM/dt (moles/hr) $\times 10^3$
5×10^{-3}	0·88		9·8	
2×10^{-3}	0·87		9·5	
10^{-3}	0·86	0·93	8·3	3·2
5×10^{-4}	0·75		6·5	
2×10^{-4}	0·46		4·0	
10^{-4}	0·24	0·49	1·6	2·8
5×10^{-5}	0·15	0·39	0·9	1·9
2×10^{-5}	0·09	0·3	0·8	1·1

(b) k_e and dM/dt: Variation of dM/dt for Methylmethacrylate with $[Fe^{3+}]^{\frac{1}{2}}$ is given in Table 2 for two intensities.

TABLE 2

Intensity $Nh\nu$/hr. $\times 10^5$	$[Fe^{3+}]^{\frac{1}{2}}$ $\times 10^3$	dM/dt (moles/hr.) $\times 10^3$
11·2	100	3·5
	31·6	3·05
	10·0	2·8
	6·33	1·9
	4·47	1·6
	3·16	1·0
	2·0	0·55
	1·4	0·25
6·8	31·6	2·04
	10	2·15
	6·33	1·42
	4·47	0·86
	3·16	0·62
	2·0	0·35

(c) k_ε & Chain length (n): Fig. 1 graph A shows the linear variation of (n) against $k_\varepsilon^{-\frac{1}{2}}$. $k_p/k_t^{\frac{1}{2}} = 1{\cdot}3 - 1{\cdot}4$ has been evaluated from the graph A. (For significance of k_p & k_t see reaction scheme under discussion).

(ii) *Light intensity* (I): I and dFe^{2+}/dt; Results between light intensity and dFe^{2+}/dt show that for higher intensities, say

above 5×10^{-5} $N h\nu$/hr., rate of ferrous ion falls. This falling off of ferrous is due to dark back reaction between ferrous ions and chloride radicals. It will be seen in the discussion part that when this dark back reaction is taken into account the actual rate of ferrous production will be $dFe^{2+}/dt \left[1 + \frac{k_o[Fe^{2+}]}{k_i[M]} \right]$ where k_o & k_i are rate constants for dark back reaction and initiation of polymerization respectively and $[Fe^{2+}]$ is called 'mean ferrous'—this will be discussed at great length elsewhere in this paper but it will be sufficient at this stage to say that there was a more regular variation between I and $dFe^{2+}/dt \left[1 + \frac{k_o[Fe^{2+}]}{k_i[M]} \right]$ (Table 3) than between I and dFe^{+2}/dt.

TABLE 3

$[Fe^{3+}]_o = 4 \times 10^{-5}$ M; [HCl] = 0·05 N; pH — 1·3

Intensity ($N h\nu$/hr) $\times 10^5$	dFe^{2+}/dt (moles/hr) $\times 10^6$	Mean (Fe^{2+}) (molar) $\times 10^6$	dFe^{2+}/dt ($\times 10^6$)
8	0·97	6·94	1·50
6·8	0·80	5·72	1·16
5·4	0·69	4·93	0·96
3·3	0·45	3·22	0·57
2·04	0·30	2·15	0·35
1·23	0·20	1·43	0·23
0·63	0·155	1·11	0·17

(b) I & dM/dt: dM/dt was found to depend on the square root of the intensity of light (Table 4).

(c) I & (n): Chain length of the polymer varied with the reciprocal of the square root of light intensity (Graph B) (Fig. 1). $k_p/k_t^{\frac{1}{2}}$ has been evaluated as $\approx$ 1·0.

TABLE 4

[HCl] = 0·05 N; pH = 1·3; [Acrylonitrile] = 1·0 M;
[Methylmethacrylate] = 0·1 M.

$[Fe^{3+}]_o^{1/2}$	$(N h\nu/hr)^{1/2}$ Intensity $\times 10^3$	dM/dt (moles/hr.) $\times 10^3$	
		Methylmethacrylate.	Acrylonitrile
4×10^5	8·22	2·99	1·7
"	5·75	2·10	1·18
"	4·53	1·60	0·97
"	2·50	0·80	0·45
"	1·25	0·42	—
2×10^5	10·58	1·7	—
"	8·90	1·5	—
"	6·10	1·0	—
"	1·97	0·25	—
10^2	11·5	3·5	—
"	8·37	2·2	—
"	4·42	1·25	—
"	2·62	0·50	—

(iii) *Change of monomer concentration* [M]; [M] & dFe^{2+}/dt: An accurate investigation of dFe^{+2}/dt with [M] proved difficult because at very low monomer concentrations or even in the absence of any monomer the rate of ferrous production was more or less as high as at higher monomer concentrations. This is to be attributed to reactions of traces or organic impurities in distilled water or the reagents in the System with the Chloride radicals. This aspect of impurities which Kolthoff & Medalia (1949) as well

as Barb, Baxendale, Hargrave (1951) have recognised in the System, $Fe^{2+}-H_2O_2$—substrate, has been dealt with elsewhere by the author (1954) at greater length as applied to our system $Fe^{3+}X^{-}$—Vinylmonomer. The results for invariability of dFe^{2+}/dt with type and concentration of monomer at all pHs but variation with intensities or concentration of ferric ion are given in Table 5.

TABLE 5

$[Fe^{3+}]$	Intensity (Nhν/hr) $\times 10^5$	[Monomer]	pH.	$\frac{dFe^{2+}}{dt}$ (moles/hr) $\times 10^6$
10^{-2}	13·2	Acrylonitrile 1·0; 0·8-0·02 M and also nil monomer.	2; 1·7; 1·5-0·8	16-17
10^{-3}	6·9	„	„	8- 9
„	„	Methylmethacrylate 0·1 to 10 M as well as nil monomer.	„	8- 9
4×10^{-5}	„	„		0·6-0·8

(b) [M] and dM/dt: dM/dt varied more regularly with [M] (Table 6). With regard to both dM/dt as well as dFe^{+2}/dt with [M] behaviour of methacrylic acid has been found to differ slightly from methylmethacrylate or acrylonitrile. This anamolous behaviour of methacrylic acid is perhaps due to its poly-electrolyte character. Fig. 2 Graphs A & B indicate that dM/dt varies more regularly with [M] rather than $[M^2]$ for acrylonitrile and Graph C represents the anamolous behaviour of methacrylic acid.

(c) [M] and (n): The result for variation of (n) with [M] are given in Table 7 (Graph C Figure 1) and $k_p/k_t^{\frac{1}{2}}$ has been evaluated as **1·1·2.**

TABLE 6

Monomer	[M] molar	dM/dt (moles/hr) $\times 10^3$	$(dFe^{2+}/dt) \times 10^6$
Acrylonitrile	1·0	2·99	0·7 to 0·8
	0·6	1·72	„
	0·3	0·72	„
	0·1	0·31	„
	0·05	0·12	„
Methylmethacrylate	$7·6 \times 10^{-2}$	1·42	„
	$4·6 \times 10^{-2}$	0·74	„
	$3·0 \times 10^{-2}$	0·55	„
	$1·9 \times 10^{-2}$	0·30	„
	$9·7 \times 10^{-7}$	0·16	„
	$5·0 \times 10^{-3}$	0·075	„
Methacrylic acid	$9·5 \times 10^{-3}$	0·09	1·1 to 1·2
	$1·4 \times 10^{-2}$	0·15	„
	$5·9 \times 10^{-2}$	1·09	„
	0·12	2·19	„
	0·28	2·97	„
	0·43	„	„
	0·70	„	„
	0·9	„	„
	5·0	8·4	„

TABLE 7

$[Fe^{+3}] = 10^{-4}M$; $k_e = 0{\cdot}24$; $I = 6{\cdot}8 \times 10^{-5}\,N h\nu$ units/hr.

Monomer = Methylmethacrylate.

[M] molar	Chain length (n)	
	Measured	Calculated
0·095	2588	2180
0·075	1778	1634
0·05	1038	1090
0·025	496	457
0·005	327	109

(iv) Effect of Ferrous accumulated in the reaction or ferrous initially added:

It was found that dFe^{+2}/dt decreased as the mean time interval or 'mean ferrous ion' increased. 'Mean ferrous ion' may be computed from (1) ferrous ion accumulating in the reaction at a particular intensity over an interval of time or (2) ferrous accumulating at different intensities for the same time interval or (3) ferrous initially added. The decrease of dFe^{+2}/dt must be attributed to dark back reaction between Fe^{+2} and Cl giving $Fe^{+3}Cl^{-}$. Mean $[Fe^{+2}]$ is taken as ferrous present before irradiation of the System plus half ferrous produced during irradiation. From the values of mean $[Fe^{+2}]$, [M] and dFe^{+2}/dt, values for k_o/k_i as well as $k_s/k_s + k_d$ for methylmethacrylate and acrylonitrile could be calculated--(Table 8). (For significance of k_o, k_i, k_s, k_d, see reaction scheme under discussion). The decrease of dFe^{+2}/dt with (a) time, (b) increase of mean ferrous ion from initially added ferrous and (c) increase of mean ferrous at different intensities are represented by Graphs A, B and C respectively in Fig. 3.

TABLE 8

For Methylmethacrylate, $I = 4{\cdot}8 \times 10^{-5} N h\nu$/hr, and

For Acrylonitrile, $I = 6{\cdot}9 \times 10^{-5} N h\nu$/hr.

Monomer	Initially added $[Fe^{2+}]$ (molar) $\times 10^5$	Fe^{2+} (molar) $\times 10^5$ (accumulated)	Fe^{2+} (molar) $\times 10^5$ produced	Mean Fe^{2+} (molar) $\times 10^5$	$\frac{dFe^2}{dt} \times 10^6$	$\frac{k_o}{k_i}$	$\frac{k_g}{k_g + k_d}$
0·1 M. Methylmethacrylate ..	nil	18·2	55·5	46	4·35	48	0·11
1·0 M. Acrylonitrile ..	0		5·6	2·8	1·82		
	5		3·7	6·8	1·51		
	7·5		3·9	9·45	1·37	6×10^3	0·13
	10		3·7	11·85	1·3		
	25			Ferrous produced very small in comparison with initially added Fe^{+2}			
	20						

(v) *Quantum yield* :—Quantum yield $\gamma_{Fe^{++}}$ with regard to dFe^{2+}/dt in case of $Fe^{3+}Cl^-$ was found to vary with $[Fe^{3+}]$, attaining a maximum value of 0·13. This value was found to be independent of type and concentration of the monomers as well as wavelengths 313 $m\mu$ or 365$m\mu$ though it dropped steeply in the visible. Quantum yield (γ_M) with regard to dM/dt was found to depend on (i) the type and concentration of the monomer, (ii) light intensity. Results for $\gamma_{Fe^{++}}$ and γ_M are given in Table 9.

TABLE 9

$[Fe^{3+}]$	Monomer	Intensity $Nh\nu$/hr $\times 10^5$	$\gamma_{Fe^{++}}$	γ_M
10^{-2}	Methylmethacrylate (0·1 M)	13·2	0·13	26·5
10^{-2}	„	6·9	0·13	
10^{-3}	„	13·2	0·12	26·8
10^{-3}	„	6·9	0·12	42
10^{-4}	„	13·2	0·10	88
10^{-4}	„	6·9	0·10	130
4×10^{-5}		13·2	0·09	113
„	„	6·9	0·1	137
„	Methylmethacrylate (0·005 M)	6·9	0·10	7·3
„	Acrylonitrile 1·0 M	6·9	0·1	290
	0·05 M	„	0·1	12
„	Methacrylic acid 1·0 M	„	0·1	300
	0·009	„	0·1	8

Discussion

The energetics of the light absorption process $Fe^{3+}Cl^- \overset{h\nu}{\rightleftharpoons} Fe^{2+}Cl$ have been well discussed by Rabinowitch and Stockmayer (1942) and subsequently by Evans & Uri (1949). It has also been sug-

gested by Evans, Santappa and Uri (1951) that after optical transition in $Fe^{3+}X^-$ (X = OH, Cl, etc.) according to Franck Condon principle, $Fe^{2+}X$ (*aq*) would be left in non-equilibrium configuration especially of the hydration shell and would therefore dissociated into Fe^{+2} plus X with a repulsion energy of $\sim$ 50 kcal. X radicals thus produced lead to polymerization of Vinyl compounds. The experimental data presented may now be examined in the light of the following reaction scheme which is assumed and then the modes of initiation and terminating mechanisms may be concluded with fair certainty. Light absorption and primary dark back reaction $Fe^{3+}Cl^- \underset{k_d}{\overset{h\nu}{\rightleftharpoons}} Fe^{2+}Cl$; initiation of polymerization by $Fe^{2+}Cl$; $Fe^{2+}Cl \rightarrow Fe^{2+} + Cl{-}M{-}$; Separation of the product, $Fe^{2+}Cl \xrightarrow{k_s} Fe^{2+} + Cl$ and second dark back reaction, $Fe^{+2} + Cl \xrightarrow{k_o} Fe^{+3} + Cl^-$, k_i, k_p, k_{t1}, k_{t2}, k_t, are the rate constants for initiation by Cl radicals, propagation, termination by the radical $Fe^{2+}Cl$, termination by the Cl radicals and termination by recombination of active endings respectively.

Assuming stationary concentrations for the radicals, $Fe^{2+}Cl$, Cl and the radical chains $Cl-(M)_n-$ where M = Monomer and $n = 1$ to ∞, it can be shown if (i) $Fe^{2+}Cl$ initiates as well as terminates (disproportionation) the chains, then,

$$dFe^{2+}/dt = \frac{k_\varepsilon I k'_i[M]}{k_d} \text{ and } dM/dt = k_p k'_i[M]^2/k_{t1}$$

(ii) $Fe^{2+}Cl$ initiates and termination is by recombination, then dFe^2/dt is same as in (i) but $dM/dt = k_p[M]^{3/2}\{k'_i k_\varepsilon I/k_t k_d\}^{\frac{1}{2}}$

(iii) Cl radicals initiate as well as terminate (disproportionation) the chains then,

$$dFe^{2+}/dt = \frac{k_s k_\varepsilon I}{k_d + k_s}\left\{\frac{k_i[M]}{k_i[M] + k_o[Fe^{+2}]}\right\}$$

and $dM/dt = k_p k_i[M]^2/k_{t2}$

(iv) Cl radical initiates but termination is by recombination then, dFe^2/dt is same as in (iii) but $dM/dt = \frac{k_p[M]}{k_t^{\frac{1}{2}}}\left(\frac{K_s k_i I}{k_s + k_d}\right)^{\frac{1}{2}}$

If $Fe^{2+}Cl$ initiates polymerization then according to (i) or (ii)

quantum yield for ferrous ion must go on increasing as the concentration of monomer increases and must not attain a constant value below unity. On the other hand if Cl radicals initiate, then, according to (iii) or (iv) quantum yield for ferrous must go on increasing as the concentration of the monomer is increased and when $k_i[M] \gg k_o[Fe^{2+}]$, $\gamma_{Fe^{2+}}$ becomes independent of monomer concentration and is represented by a constant quantity, $k_s/(k_s + k_d)$. In our experiments with $Fe^{3+}Cl^-$ a constant quantum yield of $\sim 0{\cdot}10$ to $0{\cdot}13$ was obtained (Table 3, this value being almost independent of type and concentration of monomer. That $\gamma_{Fe^{2+}}$ is as high even in the absence of any monomer must be attributed to the reaction of Chloride radicals with organic impurities in the system and any possibility of photo-oxidation of water at the wave lengths and intensities of lights used in the experiments, must be very remote if not completely excluded. Therefore rate of ferrous production will be correctly represented by (iii) or (iv),

$$dFe^{2+}/dt = \frac{k_s k_\varepsilon I}{k_d + k_s} \left\{ \frac{k_i[M]}{k_i[M] + k_o[Fe^{2+}]} \right\}$$

The applicability of this equation was further confirmed by

(1) a regular variation of dFe^{2+}/dt with k_ε (Table 1).

(2) Variation of mean Fe^{2+} with dFe^{2+}/dt (Table 8) according to the equation $1/(dFe^{2+}/dt) = \frac{k_s + k_d}{k_s k_\varepsilon I}\left(1 + \frac{k_o[Fe^{2+}]}{k_i[M]}\right)$ from which (a) k_o/k_i for methylmethacrylate $= 48$; for acrylonitrile $= 6 \times 10^3$ and (b) $\frac{k_s}{k_s + k_d} \approx 0{\cdot}10$ to $0{\cdot}13$ have been calculated.

And (3) non-uniform variation of dFe^{2+}/dt with light intensity because of secondary dark back reaction at higher light intensities. But with $dFe^{2+}/dt \left(1 + \frac{k_o(Fe^{2+})}{k_i[M]}\right)$ which takes into account the dark back reaction uniform variation could be observed even at higher light intensities (Table 3). It is therefore concluded that Cl radicals initiate polymerization.

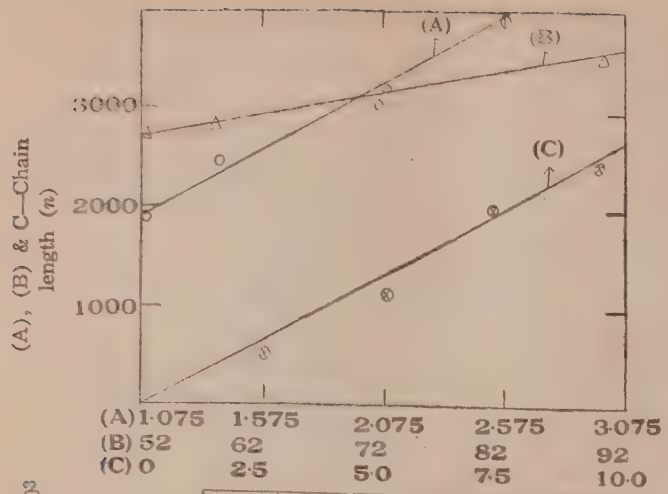


Fig. 1.

(A) $(k\varepsilon)^{-1/2}$;

(B) (Intensity)$^{-1/2}$, $\times 10^{-3}$;

(C) $[M] \times 10^3$.

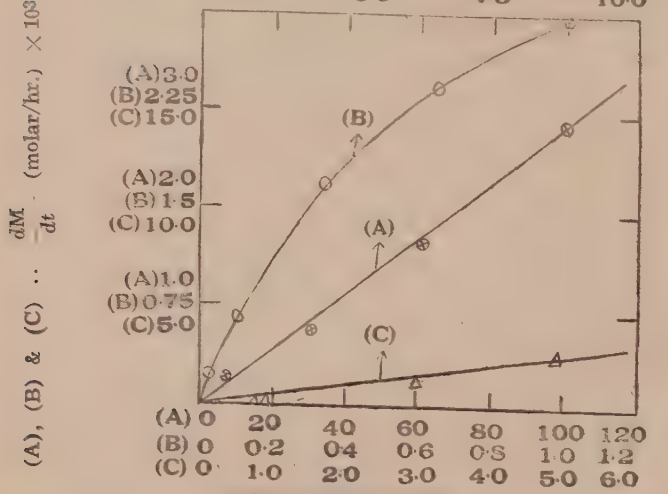


Fig. 2.

(A) . . [M] (molar) $\times 10^2$;

(B) . . $[M]^2$ (molar)^2

(C) (molar) $\times 10^3$

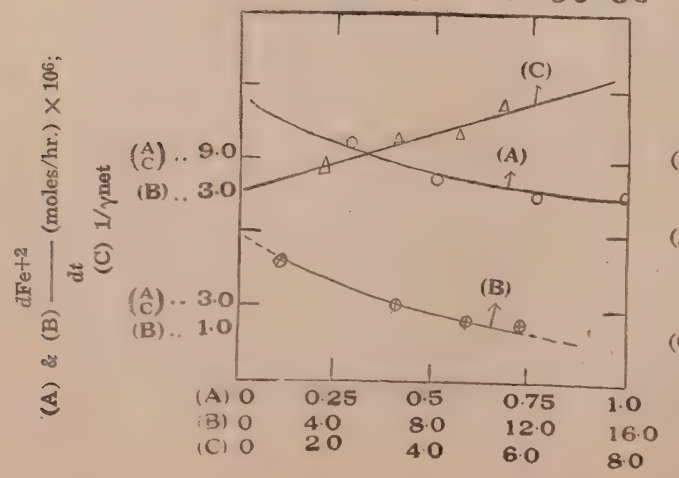


Fig. 3.

(A) Meantime on hours;

(B) Mean Fe^{+2} from initially added Fe^{+2};

(C) Mean Fe^{+2} from different intensities.

LEGENDS FOR THE FIGURES

Fig. 1. Curve A shows the variation of chainlength (n) of methylmethacrylate polymer with the reciprocal of square root of light absorption fraction ($k\varepsilon^{-1/2}$) for the ion-pair $Fe^{+3}Cl^{-}$.

Curve B shows the linear variation of chainlength of methylmethacrylate polymer with reciprocal square root light intensity ($I^{-1/2}$) when $Fe^{-3}Cl^{-}$ has been used.

Curve C shows the dependence of chainlength of methylmethacrylate polymer on the concentration of methylmethacrylate monomer with $Fe^{-3}Cl^{-}$ ion pair; $I = 6{\cdot}8 \times 10^{-5}$ $Nh\nu$/hr. and $[Fe^{+3}] = 10^{-4}$M.

Fig. 2. Graph A shows the linear relation between rate of monomer disappearance and first power of monomer concentration for the System $Fe^{-3}Cl^{-}$—acrylonitrile; $[Fe^{+3}] = 4 \times 10^{-5}$M; $[HCl] = 0{\cdot}5$ N; $I = 6{\cdot}8 \times 10^{-5}$ $Nh\nu$/hr.

Graph B shows the non-linear relation between rate of monomer disappearance and square of monomer concentration ceteris paribus as graph A.

Graph C represents the relation between dM/dt and [M] and tendency for anamolous behaviour for higher concentration of methacrylic acid.

Fig. 3. Curve A shows the gradual decrease in the rate of ferrous ion production as the mean time interval increases;

$[Fe^{+3}] = 10^{-2}$M; Intensity $= 7{\cdot}7 \times 10^{5}$ $Nh\nu$/hr.;

[Acrylonitrile] $= 1{\cdot}2$ M.

Curve B shows the decrease of rate ferrous ion production with the increase of 'mean ferrous ion'; $[Fe^{3+}] = 10^{-4}$M;

Intensity $= 6{\cdot}9 \times 10^{-5}$ $Nh\nu$/hr; Acrylonitrile; pH $= 1{\cdot}3$.

Fig. 3. Graph C represents the linear relation between $1/\gamma$ net and 'mean ferrous ion' calculated from different intensities; $[Fe^{-3}] = 4 \times 10^{-5}$M; Methylmethacrylate; pH $= 1{\cdot}3$.

To decide the question whether terminating mechanism is one of (a) disproportionation by the radicals $Fe^{2+}Cl$ or Cl or (b) recombination of active endings, we have to consider four equations for dM/dt under (i), (ii), (iii) and (iv). It was easy to conclude that termination was by recombination of active endings when Cl radicals initiated the chains and results confirmed the equation under (iii)

$$\frac{dM}{dt} = \frac{k_p}{k_t^{\frac{1}{2}}} \left(\frac{k_s k_\varepsilon I}{k_d + k_s} \right)^{\frac{1}{2}} [M]$$

The following arguments could be adduced in support of the recombination mechanism. Regular variation of (1) $k_\varepsilon^{\frac{1}{2}}$ with dM/dt (Table 1); (2) I with dM/dt (Table 4) and (3) [M] with dM/dt (Table 6). From (1), (2), (3) by making use of known values $k_s/(k_s + k_d)$ as well as $k_\varepsilon I$ it was possible to calculate the values of $k_p/k_t^{\frac{1}{2}}$ for, acrylonitrile $= 0 \cdot 156$; methylmethacrylate $= 1 \cdot 0$ and for methacrylic acid $= 1 \cdot 56$. It was also found by chlorine estimation of the polymethylmethacrylate that two chlorine atoms were present for each chain.

Further evidence for the terminating mechanism could be obtained by a knowledge of variation of chain-length of methylmethacrylate polymer with $k_\varepsilon I$ and [M]. If termination is by disproportionation then Chain length (n) would be represented by the ratio, $n = \frac{dM}{dt}$/birth rate of the chains or $(dM/dt)\frac{dFe^{+2}}{dt}$.

On the other hand for termination by combination, $n = \frac{dM}{dt} / \frac{1}{2}$ birth rate of the chains or $\frac{dM}{dt} / \frac{1}{2} \frac{dFe^{+2}}{dt}$

Variations of chain length of polymethylmethacrylate with [M], $K_\varepsilon^{-\frac{1}{2}}$ as well as $I^{-\frac{1}{2}}$ were observed (Fig. 1). From the graphs in Fig. 1 with 'n' as a function of $K_\varepsilon^{-\frac{1}{2}} \cdot I^{-\frac{1}{2}}$ and [M] values of $K_p/K_t^{\frac{1}{2}}$ have been evaluated as $1 \cdot 2 - 1 \cdot 3$ for methylmethacrylate. Further, the measured chain lengths of methyl methacrylate polymer from viscosities using Baxendale, Bywaters and Evans' Equation, could be compared with (n) calculated from the equation given above for chain length (Table 7). The foregoing discussion proves that termination is by recombination of the active endings.

ACKNOWLEDGEMENT

I am greatly indebted to late Professor M. G. Evans, F.R.S, and Dr. N. Uri of Manchester University with whom I had many fruitful discussions with regard to ferric chloride initiator during the course of my stay there from 1948-'50.

REFERENCES

Baxendale, J. H., Bywater, S., Evans, M.G. (1946) Relation between molecular weight and intrinsic viscosities for polymethylmethacrylate, *J. Poly. Sci.*, **4**; 237.

Bowen, E. J. (1946) *The Chemical aspects of Light*, The Clarendon Press, Oxford, 1942, pp. 186.

Barb, W. G. Baxendale, J. H., George, P. & Hargrave, K. R. (1951) Reaction of ferrous and ferric ions with hydrogen peroxide, *Trans. Farad. Soc.*, **47**, 462.

Evans, M. G., Santhappa, M. & Uri, N. (1951) Photoinitiated free radical polymerization of vinyl compounds in acqueous solution. *J. Poly. Sci.*, **7**, 243.

Evans, M. G. & Uri, N. (1949) Photochemical Polymerization in aqueous solution, *Nature*, **164**, 104.

Fieser, L. F. (1924) A new absorbent for oxygen in gas analysis, *J. Amer. chem. Soc.*, **46**, 2639.

Kolthoff, I. M. & Medalia, A. I. (1949) The reaction between Ferrous iron and peroxides, *J. Amer. chem. Soc.*, **71**, 3777.

Rabinowitch, E. (1942) Electron transfer spectra, *Rev. Modern Phys.*, **14**, 112.

Rabinowitch, E. & Stockmeyer, W. H. (1942) Association of ferric ions with chloride, bromide, and hydroxyl ion. *J. Amer. chem. Soc.*, **64**, 336.

Santhappa, M. (1951) Results from author's Ph. D., thesis to the University of Manchester, (1951).*

Santhappa, M. (1954) Ferric azide ion pair as a photosensitizer in the polymerization of vinyl compounds in acqueous solution, *J. Madras University*, B, **24**, 91-116, 1954.

Santhappa, M. (1954) Impurities in certain photochemical systems involving radical in aqueous solution, *Curr. Sci.*, **5**, 145.

* Photo initiated free radical polymerization of vinyl compounds in acqueous solution.

REVIEW

EXPERIMENTAL COLLEGE PHYSICS: By M. W. White and K. V. Manning, New Third Edition, pp. xii + 347, McGraw-Hill Book Co., 1954, Price $ 5·00.

This is basically a laboratory manual for experiments in courses on general physics and the contents would cover the requirements for the B.Sc. degree of our universities. But the book differs materially in its treatment from the usual text-books of laboratory physics which are adopted in our colleges. It deals in great detail with the proper approach to an experiment—namely the planning of an experiment, the choice of the suitable method, the accuracy required in the readings and so on. As the authors have stated, "If the student approaches the laboratory with the thought that it offers a personal opportunity to learn by means of actual observation some of the principles of physics, to do some independent thinking, to become familiar with modern measuring equipment, and to learn the fundamentals of preparing a technical report on the results—these hours may be very profitable." This attitude towards laboratory work, both on the part of the student, and also of the teacher, is what is unfortunately lacking in many of our colleges. It is a common feature of the teaching of physics in our country that, whereas the students acquire a considerable degree of skill in the use and manipulation of equipment, they have very little knowledge of setting up the apparatus or of choosing the proper set up for the experiment concerned.

The experiments in this book are arranged with this objective in view and the instructions given for each experiment are such that an intelligent student could try out some variations of the standard method. Two preliminary chapters deal with graphical analysis and with errors and significance of measurements respectively and these could be read with profit even by honours and post-graduate students. A number of questions and problems are given at the end of each chapter, which help also to bring out the basic physical principles involved in these.

This book must find a place in the library of every college having a department of physics. Physics teachers in particular will derive considerable benefit from it, if not from the details of the experiments, at least from the methods suggested for the training of students in the procedures of experimental physics.

G. N. R.

INDIAN COUNCIL OF MEDICAL RESEARCH

COLONEL AMIR CHAND TRUST PRIZES FOR MEDICAL RESEARCH.

LIEUT-COLONEL AMIR CHAND, ex-Principal, Lady Hardinge Medical College, New Delhi, has made a munificient donation of Rs. 50,000/- to the Indian Council of Medical Research for the purpose of awarding prizes for the best published research work in the field of medical sciences. The Governing Body of the Council has constituted a Trust called the, 'Colonel Amir Chand Trust' for the administration and management of the Fund.

SIX PRIZES, of almost equal value, of which some may be in the form of medals, shall be awarded annually on an All-India basis for the best published research work in any subject pertaining to all fields of medical sciences in general including clinical research. The term 'Clinical Research' will imply research into the mechanism and causation of disease, including its prevention and cure. It covers not simply work in patients in hospitals, but also field studies in epidemiology and social medicine and observations in general practice.

THREE of the prizes will be known as, 'BASANTI DEVI AMIR CHAND PRIZE' and the other THREE, 'SHAKUNTLA AMIR CHAND PRIZE'.

OUT OF THE SIX PRIZES, two shall be awarded to graduates of not more than ten years standing, counting from the date of graduation, provided that the work for which the prizes are to be awarded is of approved merit.

THE COMPETITORS for the prizes may be **medical or non-medical** graduates.

THE SELECTION of candidates for the award of the prizes will be made by a Selection Board appointed for the purpose.

IN A JOINT PUBLICATION the prize shall be divided between the joint workers in such proportion as the Selection Board may recommend.

IN 1954, it has been decided to make a beginning by the award of TWO PRIZES of the approximate VALUE OF Rs. 300/- each for the best research papers in medical science published by workers during the academic year 1953.

THE AWARD of the prizes will be announced at the annual meetings of the Scientific Advisory Board and the Advisory Committees of the Indian Council of Medical Research to be held in Baroda in November/December, 1954.

THE WORKERS are required to submit **15 reprints** of their papers published during 1953 and these should be sent to the SECRETARY, INDIAN COUNCIL OF MEDICAL RESEARCH, 'P' BLOCK, RAISINA ROAD, NEW DELHI, so as to reach him NOT LATER THAN THE 15TH OCTOBER, 1954.

THE PAPERS should be accompanied by a short biographical sketch and two copies of PASSPORT SIZE PHOTOGRAPHS of the worker or workers concerned.

Printed and Published by G. Srinivasachari, B.A., at G. S. Press,
21, Narasingapuram Street, Mount Road, Madras.

PUBLICATIONS

OF

THE INTER-UNIVERSITY BOARD, INDIA

		Price Rs.	A.	P.	
1.	Handbook of Indian Universities ..	3	0	0	*or* 5*s*
2.	Facilities for Oriental Studies and Research at Indian Universities ..	0	8	0	
3.	Facilities for Scientific Research at Indian Universities ..	0	12	0	
4.	Bulletin of the Inter-University Board, India, Nos. 1 to 13 ..	1	0	0	*each*
5.	Biological Outlook on Life and its Problems. By J. ARTHUR THOMSON, M.A., LL.D., Regius Professor of Natural History, University of Aberdeen ..	0	2	0	
6.	Second, Third and Fourth Conference of Indian Universities ..	1	0	0	*each*
7.	Training of Teachers in Indian Universities ..	0	8	0	
8.	Bibliography of Doctorate Theses in Science and Arts (Accepted by Indian Universities from January 1930 and from 1934) ..	0	8	0	*each*
9.	Annual Report of the Inter-University Board for 1940-41 ..	1	0	0	

[POSTAGE AND V. P. CHARGES EXTRA]

Available from :

BANGALORE PRESS,
"LAKE VIEW", MYSORE ROAD,
BANGALORE CITY.

JOURNAL OF THE MADRAS UNIVERSITY

ISSUED THRICE A YEAR

Subscription Rs. 4 per annum

(Rs. 3 for Principals and Teachers of Colleges)

Back Numbers contain Important Contributions from well-known scholars on Literature, Philosophy, Mathematics, Botany, Zoology, History, Economics, Politics and Ethnology.

Among the Supplements are "The Origin of Saivism", "Vyasa Siksha" (Sanskrit), "History of Shakespearean Criticism", "Samkhyakarika", "Vayupurana", "Sahitya Ratnakara" (Sanskrit), "Indian Federation", and "Handloom Weaving in the Madras Presidency".

BACK NUMBERS ARE AVAILABLE

Apply to the Editor:

JOURNAL OF THE MADRAS UNIVERSITY,

University Buildings,

MADRAS.